NPS-OR-96-007

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Predicting Ship Fuel Consumption: Update

by

David A. Schrady
Gordon K. Smyth
Robert B. Vassian

July 1996

19960912 018

Approved for public release; distribution is unlimited.

Prepared for: Naval Postgraduate School
Monterey, CA 93943

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5000

Rear Admiral M. J. Evans
Superintendent

Richard Elster
Provost

This report was prepared for the Naval Postgraduate School.

Reproduction of all or part of this report is authorized.

This report was prepared by:

DAVID A. SCHRADY
Professor of Operations Research

GORDON K. SMYTH
Senior Lecturer, Dept. of Mathematics
University of Queensland, Australia

ROBERT B. VASSIAN
CDR, USN,
Dept. of Operations Research

Reviewed by:

FRANK PETHO
Chairman
Department of Operations Research

Released by:

DAVID W. NETZER
Associate Provost and Dean of Research

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1996	Technical

4. TITLE AND SUBTITLE
Predicting Ship Fuel Consumption: Update

5. FUNDING NUMBERS

6. AUTHOR(S)
David A. Schrady, Gordon K. Smyth, and Robert B. Vassian

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943

8. PERFORMING ORGANIZATION REPORT NUMBER
NPS-OR-96-007

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report is concerned with the prediction of ship propulsion fuel consumption as a function of ship speed for U.S. Navy combatant and auxiliary ships. Prediction is based on fitting an analytic function to published ship class speed-fuel use data using nonlinear regression. The form of the analytic function fitted is motivated by the literature on ship powering and resistance. The report discusses data sources and data issues, and the impact of ship propulsion plant configuration on fuel use. The regression coefficients of the exponential function fitted, tabular numerical comparison of predicted and actual fuel use data, the standard error of the estimate, and plots of actual and fitted data are given for 22 classes of Navy ships.

14. SUBJECT TERMS
Operational Navy Logistics; Ship Fuel Use Prediction

15. NUMBER OF PAGES
70

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

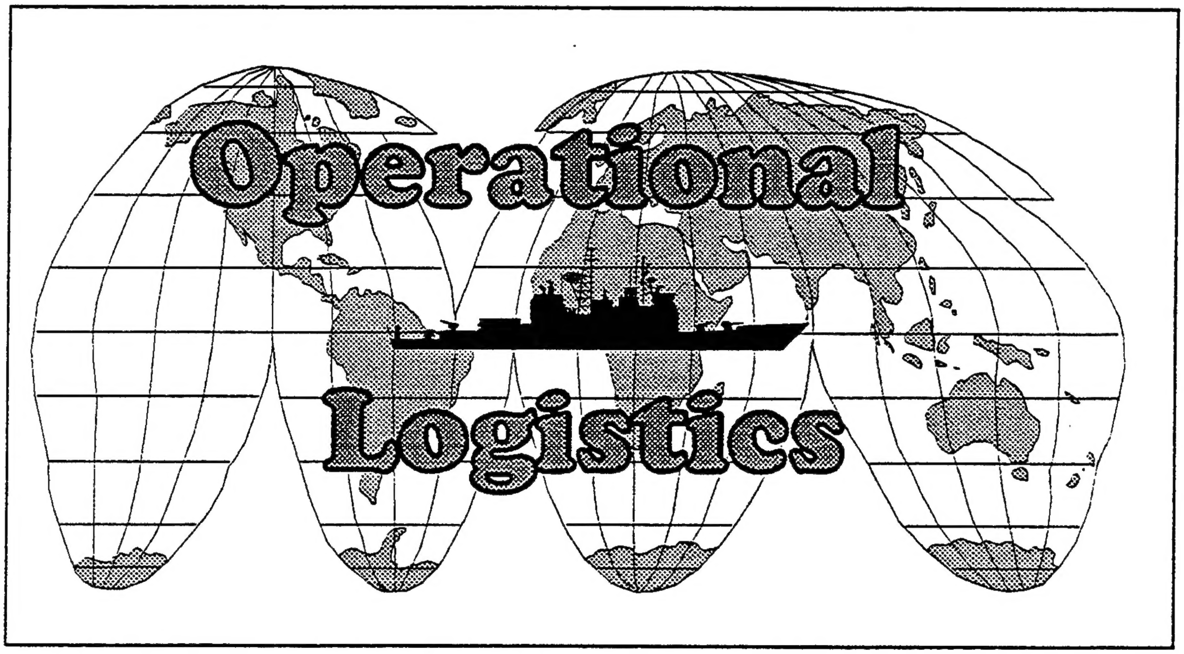

Operational
Logistics

Table of Contents

PREDICTING SHIP FUEL CONSUMPTION

1. INTRODUCTION

This report is concerned with predicting the fuel consumption (DFM/F-76) of U.S. Navy ships. Fuel consumption will be stated in gallons per hour as a function of speed for each class of ship. A data analysis approach is taken with reference made to the hydrodynamics of ship resistance and powering requirements as it motivates the analytical form of the function which is fitted to the data. Given that sea trials are conducted and that data is taken on fuel consumption for a given speed and class of ship, and that these observations are made for a number of different speeds, one can attempt to fit the speed-fuel use data with an analytic function using nonlinear regression. This is what is meant by a data analysis approach.

The reason this analysis was undertaken relates to operational logistics and the need to estimate ship and battle group/battle force endurance, fueling-at-sea (FAS) requirements, and tanker shuttle ship requirements to sustain the combat logistics force (CLF) station ship. One of the authors is involved in the development of a computer-based battle group tactical logistics support system concerned with planning, tracking, and predicting fuel and ordnance consumption and replenishment. The system requires analytical functions from which to compute predicted ship fuel consumption.

This report is an update of an earlier (1990) report on the same subject, Ref (1). This report omits much of the analysis detailed in the earlier report, omits results on ship classes decommissioned by the Navy, and includes results for ship classes brought into service since 1990. Also the

form of the analytic fuel use prediction function fitted by regression has been changed from a power function to an exponential form resulting in smaller standard error of the prediction.

2. SHIP FUEL CONSUMPTION DATA

2.1 Data Sources

Data on ship fuel consumption as a function of speed for all major USN ship classes are published. Sources include the old NWIP 11-20(D), Ref (2), NWP 11-1 (Combatants), Ref (3), NWP 11-2 (Auxiliaries), Ref (4), and the new NWP 65 series. Additionally, data on the DD-963 class ships was obtained from the Surface Warfare Officer School, Newport Ref (5), and data on amphibious warfare ships was obtained from COMNAVSURFPAC and PHIBRONs 7 and 9, Ref (6), Ref (7), and Ref (8). Data on newly commissioned ship classes has been provided by the NAVSEA Propulsion Branch.

2.2 Data Issues

Issues regarding such data include 1) the amount of speed-fuel use data available, 2) the range of ship speeds in the data, and 3) the consistency of the data when there are multiple sources of data for the same ship class.

With respect to the amount of data available, NWP 11-1 generally has 7 to 9 speed-fuel use pairs for each class of combatant ship. NWP 11-2 generally gives 3 to 6 speed-fuel use pairs for each class of auxiliary ship. In fitting any sort of analytical function the more data the better, and the NWP series has only minimal amounts of data; actually insufficient amounts of data for the auxiliary ship classes. The NWP 65 series is for combatant ship classes only and is inconsistent in its treatment of ship fuel consumption. For some ship classes speed-fuel use data is provided, for

one ship class a series of fuel consumption curves is provided (curves depend on plant/shaft configurations), and for some ship classes the NWP 65 document does not address fuel consumption at all. The older NWIP 11-20 provided more data, generally 15-20 speed-fuel use pairs, for the ships included in this publication. Of course important, newer classes are not included in NWIP 11-20. Because the method of fitting a continuous function to the data is regression, the amount of data essentially remains a methodological problem affecting the robustness of the fuel consumption estimation equations derived.

The second data issue is the ship speed ranges for which data exists. Generally NWP 11-1 data exists for combatant speeds above 12 knots, sometimes well above 12 knots, and NWP 11-2 data exists for auxiliary speeds above 10 knots. The lowest speeds for which NWIP data exists ranges from 6 to 12 knots. The speed range of the data is important in terms of the behavior of the regression equation at low ship speeds.

The third data issue is the consistency of ship fuel consumption data from different sources. Obviously data validity is a serious issue but one that cannot be resolved here. In actuality there are precious few sources of ship fuel consumption data and, in addition to limitations on the amount of data and the speed range covered by the data, none of the data available includes information about how the propulsion plant and shafts were being operated or the condition of the ship's hull. Where different sets of data were obtained with the ship's plant in different configurations or with a fouled rather than clean hull, or in different sea states or temperatures, one should expect different fuel consumption data.

3. METHODOLOGY

3.1 Conventional Wisdom

In fitting an analytic function to ship speed-fuel use data, it is helpful to know a priori what sort of function it is supposed to be. The conventional wisdom is that ship fuel use is a cubic function of ship speed. In connection with their own studies, the Center for Naval Analyses has used cubic polynomial regression to fit speed-fuel use data. This produces relatively high coefficients of determination, r-squared values; generally 0.97 or higher. Residuals, the differences between the actual fuel use at a given speed and the fuel use predicted by the cubic regression equation evaluated at that speed, were generally acceptable with maximum errors being on the order of 10% within the range of ship speeds contained in the data. However there is the problem of controlling the cubic equation at low ship speeds. In the CNA report, Ref (9), ship speed-fuel use data is fitted with the cubic polynomial equation,

$$F = c_o + c_1 V + c_2 V^2 + c_3 V^3 \tag{1}$$

where F is fuel use in gallons per hour and V is ship speed in knots. When cubic polynomial regression is used and data exists only for higher ship speeds, the equation can curve upward at low speeds (e.g., predicting that the ship will use more fuel at 5 knots than at 15 knots) or the curve can go negative (e.g., the coefficient c_0 is negative, at slow speeds the ship is making fuel!). Some reports get around this by noting that the fuel consumption prediction equations should only be used with ship speeds above, say , 14 knots. In reality however, speeds below 14 knots are important and one must be able to predict fuel use for speeds below 14 knots.

Our attempts to control the low speed behavior of the cubic polynomial included using in-port fuel allowances as the amount of fuel used at zero speed and spline fit routines to generate

missing low speed data, as described in Ref (1). None of these attempts to control the low speed behavior of the cubic polynomial was satisfactory. Because of this and because it is simply more satisfying to try to determine the theoretical relationship which should exist between ship speed and fuel consumption, some effort was made to study the subject of ship powering and resistance.

3.2 Theory of Ship Powering and Resistance

Figure 1 is intended to illustrate the relationship between fuel input and ship speed. Fuel is consumed by a prime mover (fossil fuel steam turbine, gas turbine, or diesel) and the output is brake horsepower (BHP). This power generally acts through gearing to a shaft or shafts and ultimately to propellers, the output being effective horsepower (EHP). The EHP acts to move the hull through the water at some speed completing the chain from fuel input to ship speed achieved. The EHP must equal the total resistance generated by the ship moving through the water. For displacement hulls, total resistance has two principal components: friction resistance and wave-making resistance. At slow speeds friction resistance dominates, but at higher speeds wave-making resistance dominates and increases rapidly as hull speed is approached. EHP is the horsepower required to equal the ship's total resistance at a given speed.

In 1876, William Froude in England gave the formula for EHP as, Ref (10):

$$EHP = \frac{C_T}{2} \rho \frac{S}{550} V^3 \tag{2}$$

where

C_T = coefficient of total resistance,

ρ = fluid density in slugs per cubic foot,

S = wetted area of the hull in square feet, and

550 = one horsepower in foot-pounds per second.

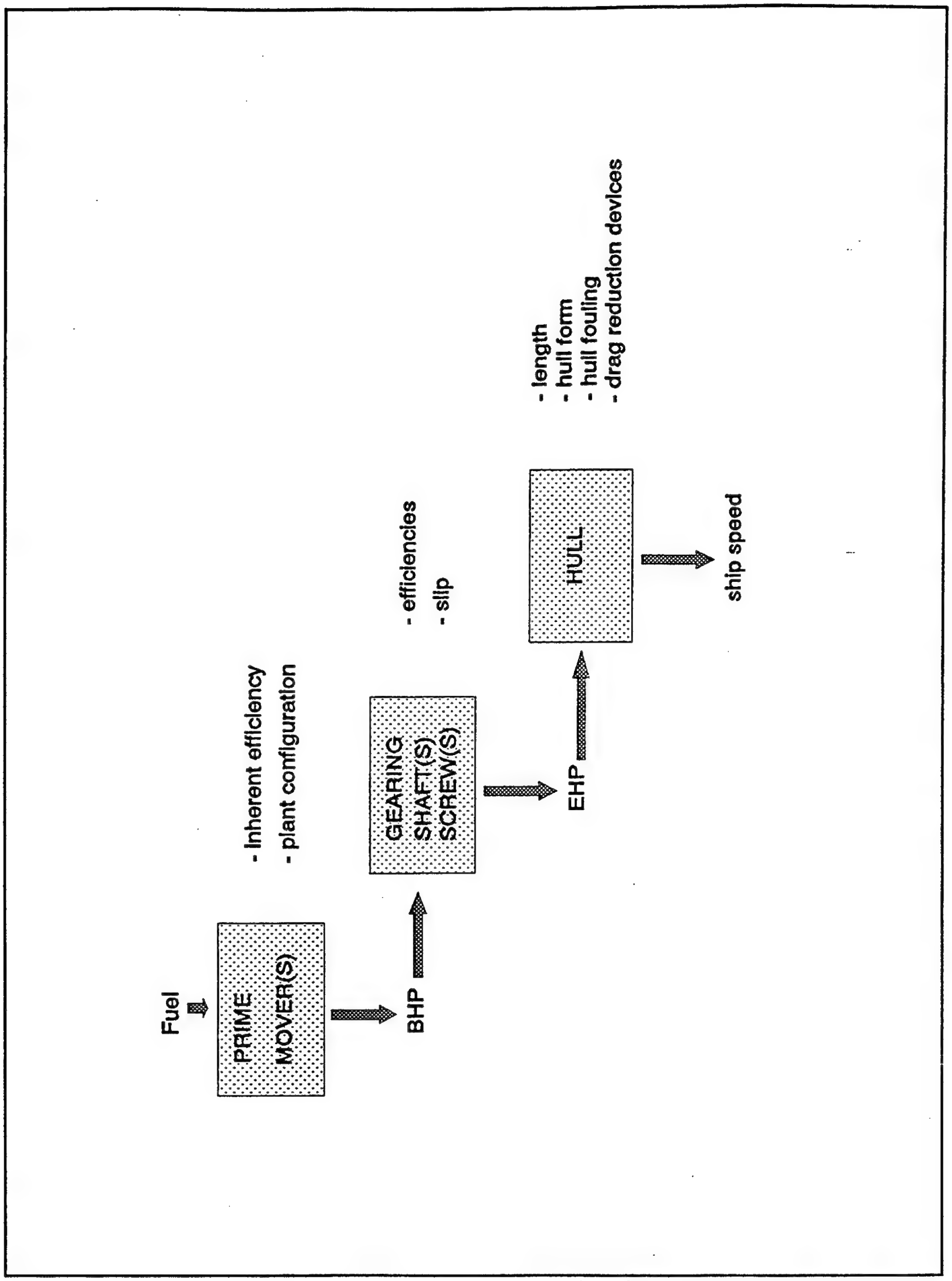


Figure 1. Ship Propulsion System

Thus we know that the EHP required is theoretically a cubic function of ship speed.

An alternate explanation of this relationship is that hull resistance is proportional to speed squared, and that resistance times velocity is by definition power. Either way it follows that EHP depends on the cube of ship speed. Further it is assumed in current practice, Ref (11), that EHP is a constant fraction of BHP. The ultimate relationship between fuel input and ship speed is then cubic in ship speed, but further depends on the relationship between fuel input and BHP produced by the prime mover. Thus more must be said about the relationship between fuel consumption and output power for the types of prime movers used in U.S. Navy ships; diesel, steam turbine, and gas turbine.

One would ideally like to know the theoretical relationship between fuel input and horsepower output. After extensive discussion with mechanical and naval engineers and a review of applicable literature, it was determined that no single theoretical model (something like Froude's result) of fuel consumption as a function of power output exists. The relationship is always specific to 1) the type of prime mover (steam turbine, gas turbine, or diesel), 2) the particular prime mover in question (manufacturer, size, specific characteristics), and 3) how the prime mover is actually operated in its application.

Even though there is no single theoretical model for fuel consumption as a function of power output, some indication of this relationship can be gained from examining the characteristics of some specific prime movers. The approach to describing fuel consumption as a function of horsepower was to use specific fuel consumption (SFC) vs. horsepower curves for each type of prime mover. SFC is given in, or can be converted to, units of gallons per horsepower-hour. Multiplying SFC by horsepower yields the desired fuel consumption measure, gallons per hour. A typical SFC versus

horsepower curve shows a function in which SFC is quite large for low output (horsepower) and falls rapidly with increasing output reaching something of a lower bound, and possibly rising modestly as maximum output is approached. When converted to gallons per hour versus horsepower the relationship is typically a function which is a monotone increasing convex curve for steam turbine and diesel prime movers. A gas turbine, however, is different in that it is most efficient at maximum output. The gallons per hour versus horsepower relationship for a gas turbine is concave. In general, in no case are such curves linear.

It is assumed that the concave or convex fuel gallons per hour verses horsepower function may be described by the equation

$$F = b_0 + b_1 e^{b_2 BHP} \tag{3}$$

where F is fuel use in gallons per hour and BHP is brake horsepower. Equation (3) is only an intermediate form which will affect the form of the analytic function actually fitted to the speed-fuel use data. In the earlier report, Ref (1), Equation (3) had the form

$$F = b_0 + b_1 [BHP]^{b_2}.$$

While the form of Equation (3) is arbitrary so long as the form can produce monotone increasing convex or concave functions over the appropriate ranges, use of the exponential form for Equation (3), when combined with Froude's result, Equation (2), produces superior prediction functions.

3.3 Theoretical Model of Ship Fuel Consumption verses Speed

In Section 3.2 it was shown that theory dictates that the power required to move a displacement hull through the water at velocity V was proportional to V^3. It was also indicated that Effective Horsepower is a constant fraction less than on of Brake Horsepower. Also in that section, it was stated that there is no single theoretical relationship for the conversion of fuel to horsepower

in a prime mover. The relationship depends on all the prime mover specifics and how it is actually operated in a given application.

Referring again to Figure 1 and Equation (2), we know that

$$EHP = \frac{C_T}{2} \rho \frac{S}{550} V^3 = cV^3 .$$

If we assume

$$EHP = a \cdot BHP$$

where 0 < a < 1, then

$$BHP = \frac{EHP}{a} = \frac{cV^3}{a} = dV^3$$

Then if, as in Equation (3),

$$F = b_0 + b_1 e^{b_2 BHP}$$

it follows that

$$F = b_0 + b_1 e^{b_2 [dV^3]}$$

or finally

$$F = p_0 + p_1 e^{p_2 V^3} \qquad (4)$$

where

$$p_0 = b_0$$

$p_1 = b_1$, and

$$p_2 = b_2 d .$$

In application the coefficients p_0 , p_1 , and p_2 will be determined by regression performed on ship class speed-fuel use data. Equation (4) will be referred to as an exponential model of fuel use as a function of ship speed.

4. DATA FITTING AND RESULTS

4.1 Data Source

The source of the data used in developing the fuel use prediction for each ship class is indicated on the data page for the ship class in the Appendix. Generally the source with the largest number of speed-fuel use data pairs is used. For the newer classes of ships, however, ship trials data obtained from the NAVSEA Propulsion Branch is used and is the only known source.

4.2 Zero Points

The problem with the low speed behavior of the cubic polynomial prediction function has already been discussed. An early attempt to control low speed behavior lead us to try to determine how much fuel a ship (ship class actually) burned at zero speed. Such data is not available and we took as a surrogate the published In-Port Steaming Allowances obtained from CINCLANTFLT. These were referred to as "zero points". Though the power functions controlled low speed behavior very much better than the cubic polynomial functions, there was a minor problem in that the predicted low speed fuel use values were excessive for the CV-63, DD-963, and CG-47/52 classes. Zero points were not used in producing the power function results in Ref (1) because they did not improve low speed behavior significantly and did tend to produce predictions in the speed range for which data was available which were not as good as the regressions run without zero points.

Still the excessive low speed fuel use of the three ship classes noted above, lead to reevaluating the use of zero points and a decision to use them this time; this time was the first time for the four ship classes introduced since 1990 (LHD-1, DDG-51, AOE-6, and PC-1). In the process of doing this one of the authors, Gordon Smyth, came along and said that he had been using Ref (1) in teaching the Data Analysis course in the Operations Research and Operational Logistics curricula at NPS and that he found that an exponential functional form produced better fits than did the power functions. Thus the form of the relationship between fuel input and horsepower output was changed and resulted in the exponential expression shown in Equation (4) for the relationship between fuel use and ship speed. As before the final decision is that the best results obtain from not using the In-Port Steaming Allowances as a proxy for fuel use at zero speed.

4.3 Plant Configuration

All ship classes whether steam, diesel or gas turbine are powered by pairs or multiple pairs of engines. Plant configuration refers to the number of engines which are 'on line' and working to propel the ship through the water. A ship with, say, four LM 2500 gas turbine engines may be operated with a single engine, two engines, or four engines on line. In general a ship must use more power, and more engines to make greater speed, but the speed ranges of each mode of plant configuration overlap. For a ship with four LM 2500 gas turbines and three plant configurations (single engine, two engine, and four engine), there are really three different speed-fuel use curves. While this phenomenon is real and exists for all ship classes regardless of their type of prime mover, the regressions produced here correspond to a single speed-fuel use relationship which "smoothes" the transitions between plant configurations.

Still one could fit separate fuel prediction functions depending on plant configuration. One study, Ref (9), suggested using three different fuel use prediction functions depending on ship speed. This would require more detailed information and more computational complexity for each ship class. However, given the total number of variables involved (sea state, hull condition, plant configuration, and many others for which specific information will not exist off-ship), these complications seem unwarranted.

4.4 The Regression Software

The statistical package used to perform the regressions for each ship class was S-PLUS published by Statistical Sciences, Inc., Ref (12). This PC-based software computes the values of the three parameters of Equation (4) using the minimization of the standard error of the estimate as its fit criterion.

4.5 The Results

The results, values of the fitted regression parameters, tabulation of the numerical actual and predicted fuel use in gallons per hour as a function of speed, and plots of the actual data and the prediction function for 21 USN ship classes is presented in the Appendix.

6. CONCLUSION

As stated in the Introduction, the authors' use of ship fuel use prediction functions is in connection with a battle group logistics support system. The support system allows the planning for, tracking of, and prediction of future fuel and ordnance consumption and replenishment requirements. It can be argued that if one can predict the daily fuel use of a given ship to within 1-2% of capacity, such prediction capability is adequate and useful for the purposes intended. With fuel reserve levels

of 50% or more, fueling-at-sea (FAS) will be required every 3-7 days for most surface combatants depending on ship class and speed. Prediction errors of 1-2% of capacity per day are small enough that FAS requirements planning would indicate the correct day (but not the correct hour) on which FAS was required by a given ship. Of course the exact hour is of little real interest. Further, if the tactical situation allows daily ship reporting, daily updates of predicted values to actual values can be made eliminating the compounding of prediction errors.

Review of the difficulties involved in ever making truly accurate predictions of the fuel use of a given ship on a given day is instructive. First there are problems with the data on which any prediction function is based: few sources of data, relatively little data available from any source, little or no low speed data, and inconsistency between different data sources. None of the data sources provide information on the plant condition, hull condition, temperature, sea state, etc., all of which effect fuel consumption. Difficulties in using any fuel use prediction function at sea in real operations include knowing sea state, ship speed (something that varies often throughout a given day depending upon the assigned activities of a given ship), and operational specifics which may dictate that the ship has more horsepower on line than is required for its speed at a given time; e.g., the ship is in plane guard role, the ship is in an underway replenishment evolution, the ship is navigating restricted waters, the ship is in a high threat situation, etc. These factors will not be known with any certainty by a planner or afloat logistics coordinator.

For all these reasons the question is not whether one can predict ship propulsion fuel usage accurately, but rather whether on can predict ship fuel use to a useful approximation. It was argued above that predicting ship fuel use to within 1-2% of capacity per day was adequate. Thus while there are a plethora of reasons why the fuel use prediction functions in this report will not produce

"spot on" accurate estimates of the fuel use of a given ship on a given day, it is asserted that they do in fact produce operationally adequate and useful estimates.

REFERENCES

1. D.A. Schrady, D.B. Wadsworth, R.G. Laverty, and W.S. Bednarski, *Predicting Ship Fuel Consumption,* Naval Postgraduate School Technical Report NPS-OR-91-03, October 1990

2. Naval Warfare Information Publication 11-20(D), Volume II, *Missions and Characteristics of U.S. Navy Ships and Aircraft (U)*, Confidential, May 1974

3. Naval Warfare Publication 11-1(B), *Characteristics and Capabilities of U.S. Navy Combatant Ships (U)*, Confidential, January 1983

4. Naval Warfare Publication 11-2(B), *Characteristics and Capabilities of U.S. Navy Auxiliary Ships (U)*, Confidential, January 1983

5. Surface Warfare Officers School, *DD-963 Class Speed/RPM/Pitch Tables and Fuel Curve Tabular Data*, undated (circa 1989)

6. Interview between COMNAVSURFPAC Operations Officer and LT Bednarski, 23 February 1990

7. Telephone conversation between LCDR Cate, COMPHIBRON 7, and LT Bednarski, 28 June 1990

8. Interview between RMC Provost, COMPHIBRON 9, and LT Bednarski, 23 February, 1990

9. Jodi Tryon, *Cube3: A Model for Calculating Fuel Consumption for Gas-Turbine Ships,* Center for Naval Analyses Research Memorandum CRM 86-213, October 1986

10. T.C. Gillmer and B. Johnson, *Introduction to Naval Architecture*, Chapter 11 "Ship Resistance and Powering", Naval Institute Press, 1982

11. P.F. Pucci, *Supplemental Notes for Marine Gas Turbines,* class notes, Naval Postgraduate School, January 1990

12. Statistical Sciences, Inc., *S-PLUS for Windows,* Reference Manual, 1993

APPENDIX

This Appendix presents the fuel use prediction functions for 22 U.S. Navy ship classes and is organized as follows:

Ship Class

CV-63/67
CG-47/52
DDG-51
DD-963/DDG-993
FFG-7
PC-1
LCC-19
LHD-1
LHA-1
LPH-2
LPD-4/AGF-11
AGF-3
LSD-41
LSD-36
AD-37
AOE-6
AOE-1
AOR-1
TAE-26
TAFS-1
AO-177(J)
TAO-187

Class: CV-63/67
Source: NWIP 11-20(D)

Speed	KGal.Hr	Predicted
0.0	NA	1928.3
1.0	NA	1928.6
2.0	NA	1931.1
3.0	NA	1937.9
4.2	1653	1954.6
5.0	NA	1972.7
6.4	1905	2021.7
7.0	NA	2050.7
8.7	2194	2164.6
9.0	NA	2190.1
10.0	NA	2289.1
11.1	2482	2424.7
12.0	NA	2559.3
13.4	2887	2816.8
14.0	NA	2947.3
15.6	3392	3363.0
16.0	NA	3483.9
17.7	4143	4086.1
18.0	NA	4208.7
19.9	5081	5118.6
20.0	NA	5173.5
21.0	NA	5766.9
22.1	6510	6522.0
23.0	NA	7231.2
24.2	8503	8325.9
25.0	NA	9164.8
26.3	11014	10747.9
27.0	NA	11730.8
28.3	14146	13845.6
29.0	NA	15165.4
30.3	17842	18022.4
31.9	21941	22438.4
32.0	NA	22753.9
33.2	26662	26973.4
34.2	31672	31201.4
35.0	NA	35151.4

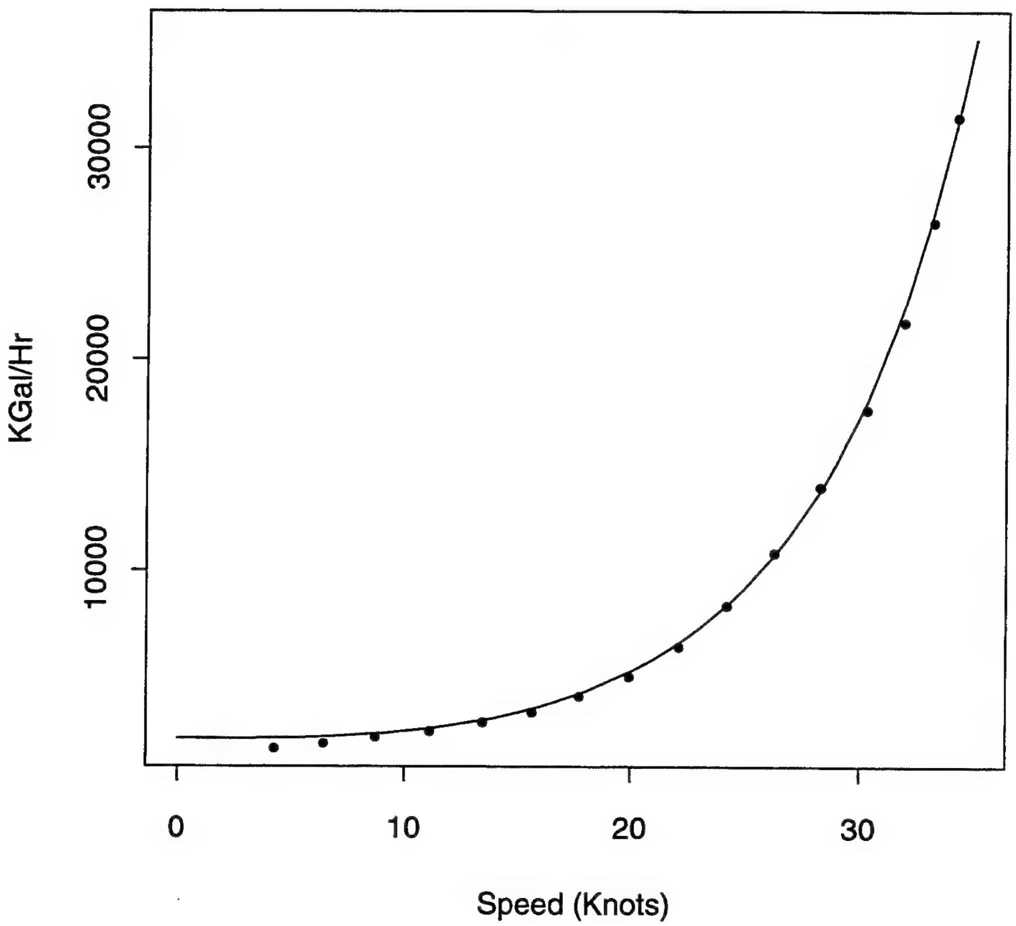
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	32.6666	1.41696	23.05400
	-8937.6000	894.86500	-9.98766
	10865.9000	822.30100	13.21400

Residual standard error: 264.591 on 13 degrees of freedom

CV-63/67



Class: CG-47/52
Source: NAVSEA Trials

Speed	KGal.Hr	Predicted
0	NA	786.4
1	NA	786.4
2	NA	787.0
3	NA	788.6
4	NA	791.7
5	NA	796.8
6	NA	804.4
7	NA	815.0
8	NA	829.3
9	NA	847.7
10	NA	871.0
11	NA	899.7
12	NA	934.6
13	NA	976.5
14	NA	1026.3
15	NA	1085.1
16	1076	1154.0
17	1172	1234.3
18	1287	1327.6
19	1414	1435.8
20	1700	1561.0
21	1827	1705.7
22	1966	1873.0
23	2116	2066.5
24	2272	2290.5
25	2427	2550.2
26	2605	2852.1
27	3364	3204.0
28	3687	3615.2
29	4065	4097.7
30	4622	4666.0
31	5372	5338.2
32	NA	6137.0
33	NA	7091.3
34	NA	8237.4
35	NA	9621.9

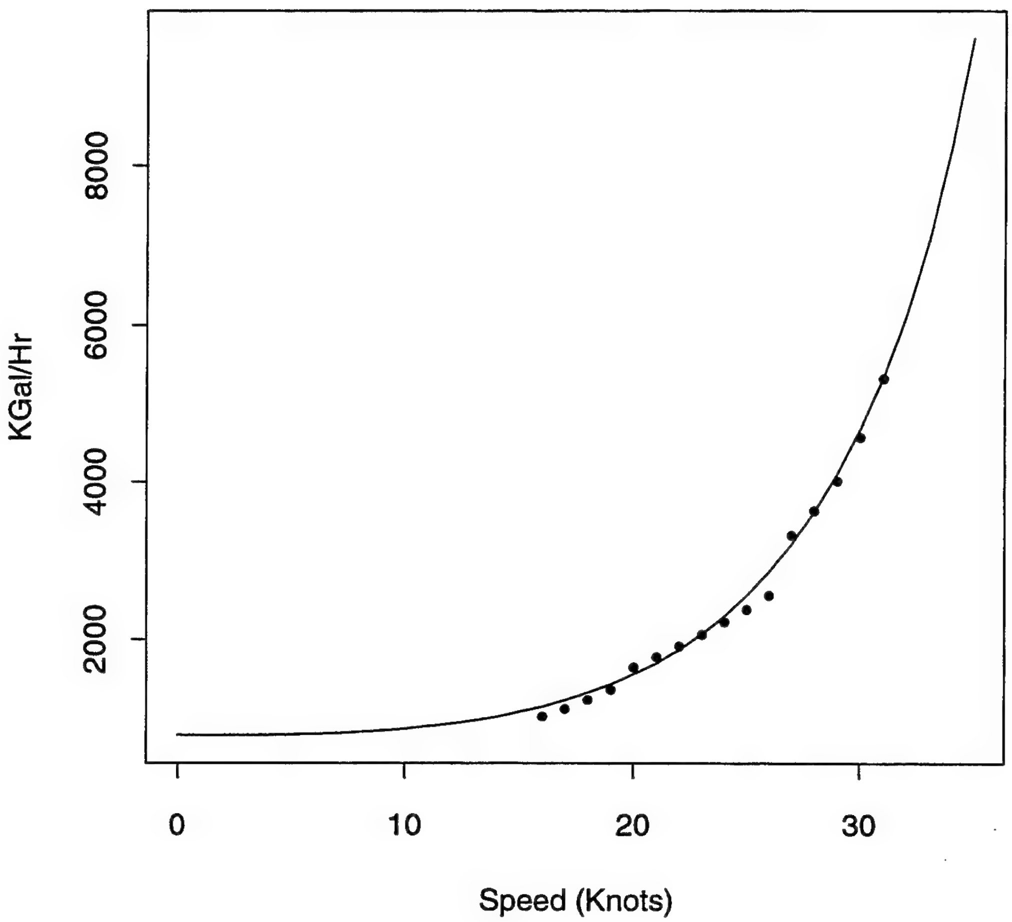
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	37.4831	6.4865	5.77862
	-1429.0400	727.9950	-1.96298
	2215.3900	646.2490	3.42807

Residual standard error: 113.925 on 13 degrees of freedom

CG-47/52



Class: DDG-51
Source: NAVSEA Trials

Speed	KGal.Hr	Predicted
0	NA	615.2
1	NA	615.3
2	NA	615.8
3	NA	617.1
4	NA	619.8
5	NA	624.1
6	NA	630.7
7	NA	639.8
8	NA	652.1
9	613	668.1
10	658	688.2
11	700	713.3
12	741	743.8
13	784	780.8
14	832	825.0
15	886	877.6
16	950	939.8
17	1025	1013.2
18	1115	1099.5
19	1222	1200.9
20	1348	1320.1
21	1496	1460.2
22	1669	1625.3
23	1920	1820.1
24	2070	2050.7
25	2280	2324.9
26	2460	2652.0
27	2780	3044.3
28	3730	3517.3
29	4220	4091.0
30	4800	4791.2
31	5600	5651.6
32	NA	6716.8
33	NA	8045.6
34	NA	9716.9
35	NA	11837.3

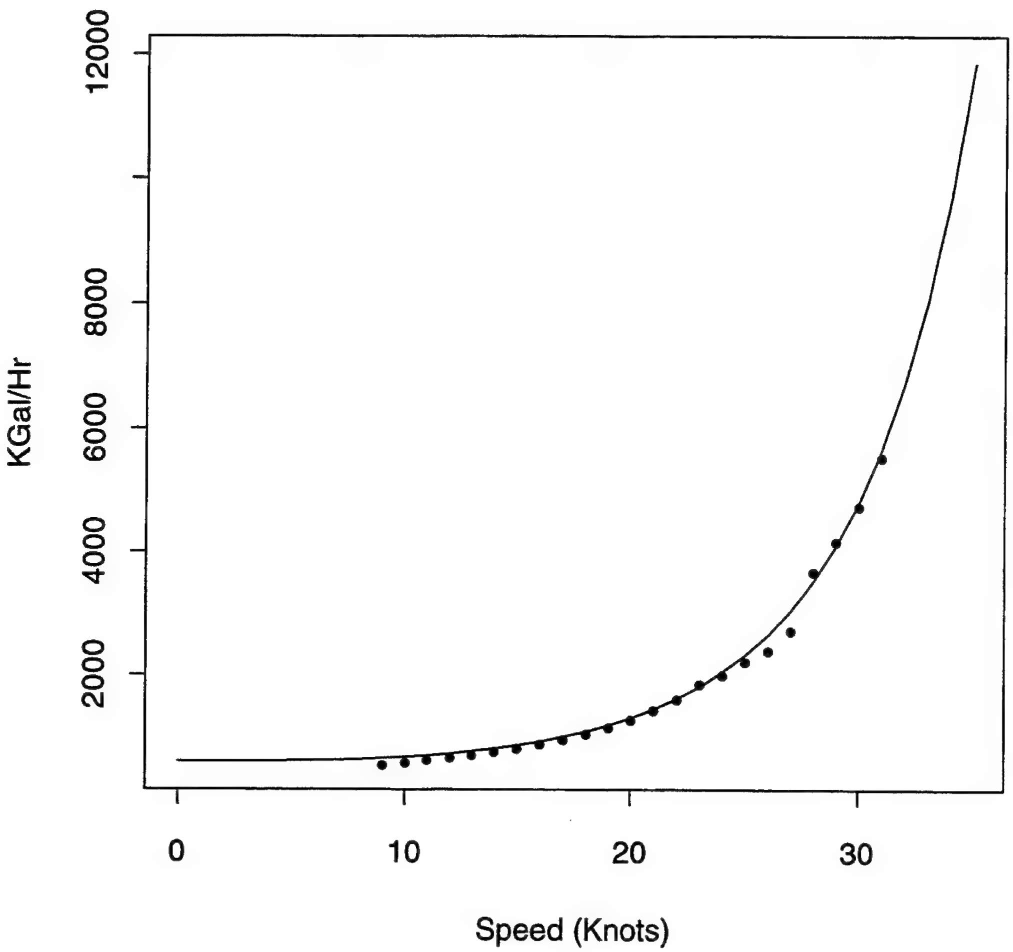
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	51.5925	3.76872	13.68960
	-764.4330	220.15400	-3.47226
	1379.6200	191.05800	7.22095

Residual standard error: 98.2004 on 20 degrees of freedom

DDG-51

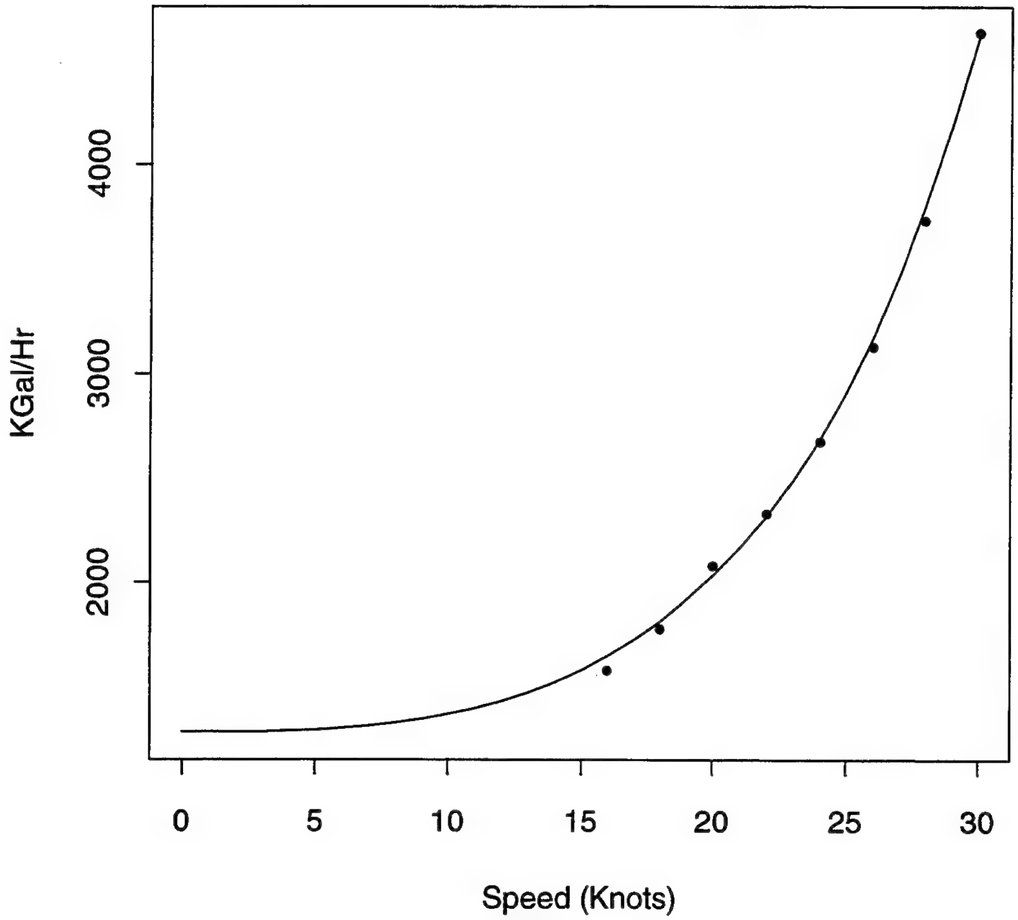


Class: DD-963/DDG-993
Source: NWP 11-1(B)

Speed	KGal.Hr	Predicted
0	NA	1285.0
1	NA	1285.1
2	NA	1285.7
3	NA	1287.3
4	NA	1290.4
5	NA	1295.5
6	NA	1303.2
7	NA	1313.9
8	NA	1328.3
9	NA	1346.8
10	NA	1370.0
11	NA	1398.7
12	NA	1433.4
13	NA	1474.9
14	NA	1523.9
15	NA	1581.4
16	1600	1648.3
17	NA	1725.7
18	1800	1814.8
19	NA	1917.0
20	2100	2034.0
21	NA	2167.6
22	2350	2319.9
23	NA	2493.3
24	2700	2690.9
25	NA	2915.8
26	3150	3172.3
27	NA	3464.8
28	3750	3799.1
29	NA	4181.8
30	4650	4620.8
31	NA	5125.6
32	NA	5707.9
33	NA	6381.4
34	NA	7163.3
35	NA	8074.2

```
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
         Value  Std. Error   t value
b     27.0667     5.42175   4.99225
  -1812.9200   951.22300  -1.90588
   3097.9700   898.85400   3.44658

Residual standard error: 48.2814 on 5 degrees of freedom
```

DD-963/DDG-993

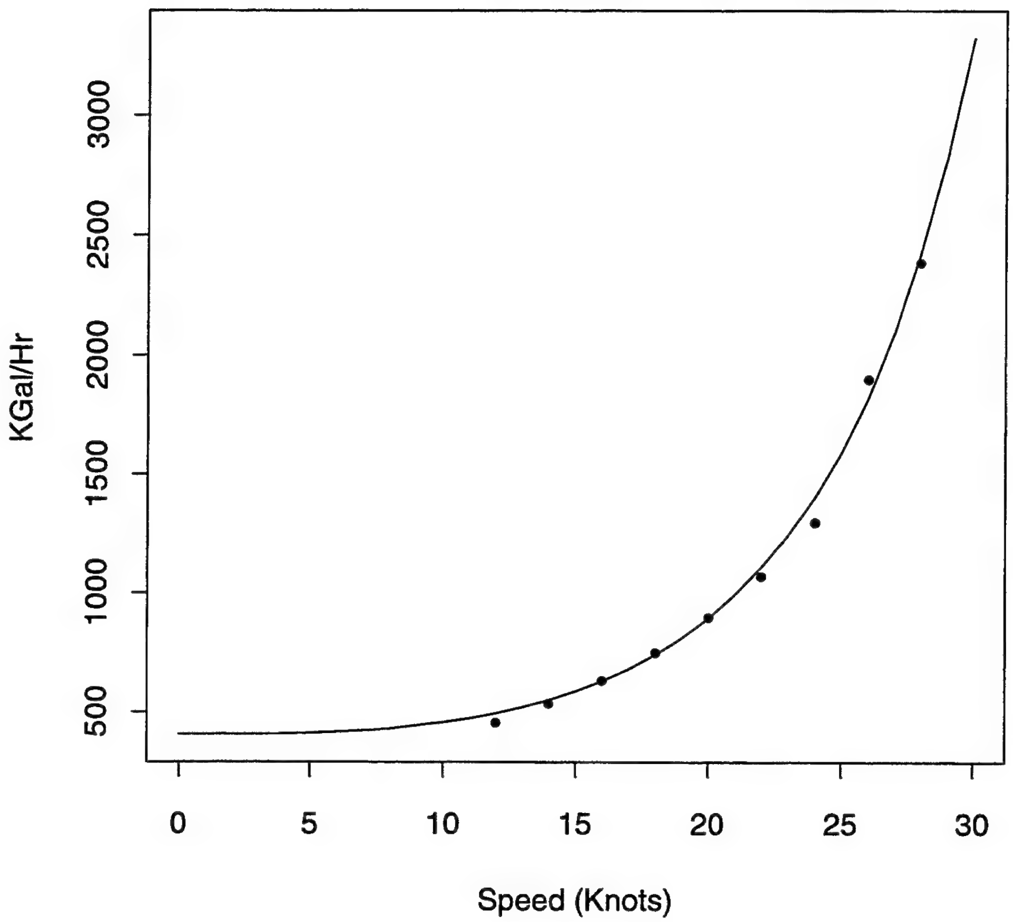


Class: FFG-7
Source: NWP 11-1(B)

Speed	KGal.Hr	Predicted
0	NA	405.4
1	NA	405.5
2	NA	405.8
3	NA	406.7
4	NA	408.6
5	NA	411.6
6	NA	416.1
7	NA	422.5
8	NA	431.0
9	NA	442.1
10	NA	456.1
11	NA	473.4
12	472	494.6
13	NA	520.2
14	553	550.9
15	NA	587.4
16	649	630.6
17	NA	681.6
18	764	741.5
19	NA	811.9
20	914	894.7
21	NA	992.1
22	1087	1106.9
23	NA	1242.4
24	1313	1402.9
25	NA	1593.8
26	1917	1821.7
27	NA	2095.2
28	2400	2425.1
29	NA	2825.5
30	NA	3314.6
31	NA	3916.1
32	NA	4661.4
33	NA	5592.0
34	NA	6763.5
35	NA	8251.4

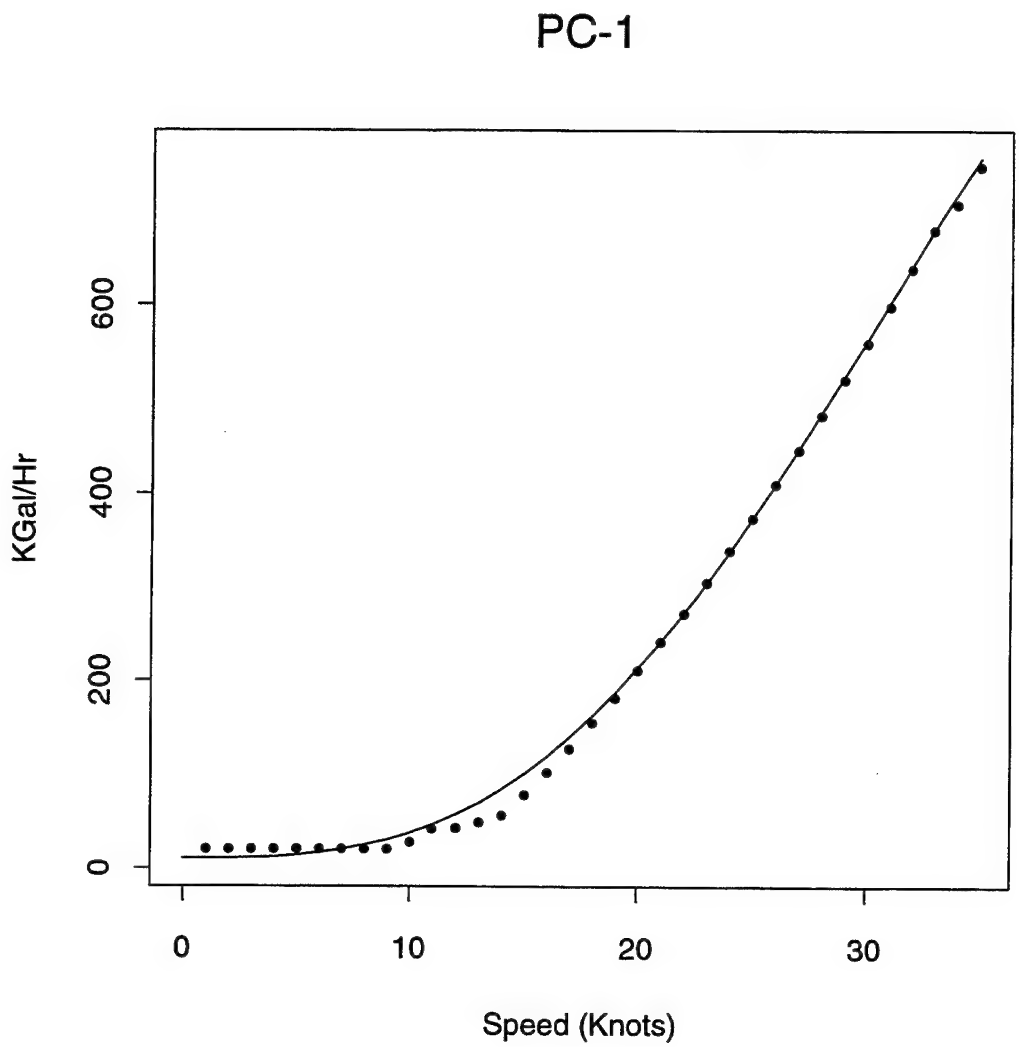
```
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
        Value Std. Error   t value
b    51.8843     11.1081   4.67084
   -545.7160    382.7230  -1.42588
    951.1170    344.6340   2.75979

Residual standard error: 57.6276 on 6 degrees of freedom
```

FFG-7

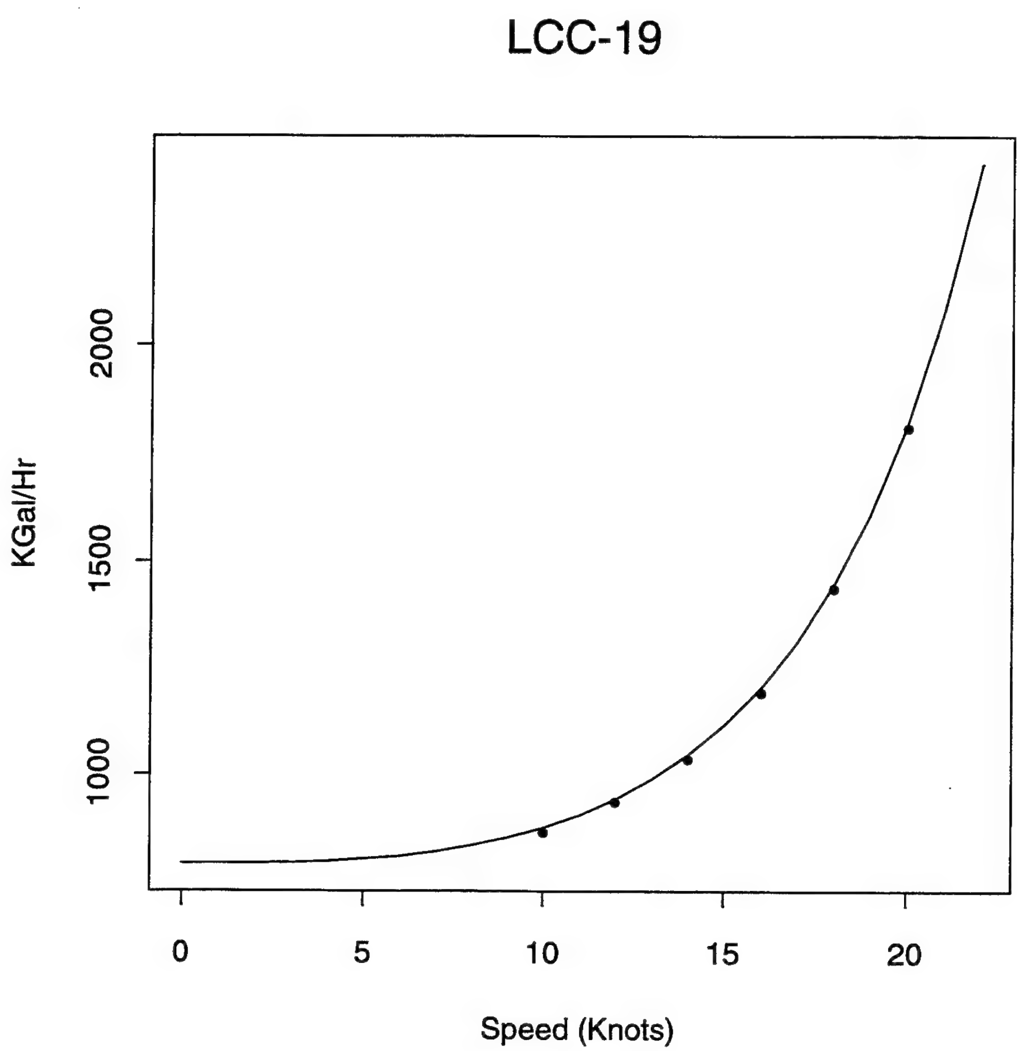


KGal/Hr
500
1000
1500
2000
2500
3000
0
5
10
15
20
25
30
Speed (Knots)

```
 Class: PC-1
Source: Ship tests

 Speed KGal.Hr Predicted
     0      NA      11.0
     1      25      11.0
     2      25      11.2
     3      25      11.8
     4      25      12.8
     5      25      14.5
     6      25      17.0
     7      25      20.5
     8      25      25.2
     9      25      31.2
    10      33      38.6
    11      47      47.5
    12      48      58.2
    13      54      70.7
    14      61      85.0
    15      83     101.4
    16     107     119.7
    17     132     140.1
    18     159     162.6
    19     186     187.2
    20     216     213.7
    21     246     242.2
    22     277     272.6
    23     310     304.7
    24     344     338.4
    25     378     373.5
    26     414     409.9
    27     450     447.2
    28     487     485.4
    29     525     524.1
    30     564     563.1
    31     603     602.1
    32     642     640.9
    33     683     679.3
    34     710     716.9
    35     750     753.6

Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
          Value Std. Error   t value
b    -24.3044     1.30277 -18.6560
   1158.2800    41.26510  28.0692
  -1147.2600    40.20400 -28.5360

Residual standard error: 9.24413 on 32 degrees of freedom
```


PC-1
KGal/Hr
0
200
400
600
0
10
20
30
Speed (Knots)

```
Class: LCC-19
Source: NWP 11-1(B)

 Speed KGal.Hr Predicted
     0      NA     791.6
     1      NA     791.7
     2      NA     792.2
     3      NA     793.7
     4      NA     796.7
     5      NA     801.6
     6      NA     808.9
     7      NA     819.2
     8      NA     833.3
     9      NA     851.6
    10   873.6     875.3
    11      NA     905.1
    12   945.0     942.4
    13      NA     988.6
    14  1045.8    1045.8
    15      NA    1116.2
    16  1201.2    1203.1
    17      NA    1310.5
    18  1444.8    1443.8
    19      NA    1610.0
    20  1818.6    1818.8
    21      NA    2083.1
    22      NA    2420.7
    23      NA    2856.5
    24      NA    3425.4
    25      NA    4177.4
    26      NA    5184.4
    27      NA    6552.6
    28      NA    8439.7
    29      NA   11084.6
    30      NA   14854.7
    31      NA   20325.2
    32      NA   28411.5
    33      NA   40598.4
    34      NA   59340.1
    35      NA   88773.2

Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
     Value Std. Error  t value
b 112.9410    2.80061 40.32750
   92.0583   29.36670  3.13479
  699.5530   27.14310 25.77270

Residual standard error: 2.18812 on 3 degrees of freedom
```


LCC-19
KGal/Hr
2000
1500
1000
0
5
10
15
20
Speed (Knots)

Class: LHD-1
Source: NAVSEA Propulsion Branch

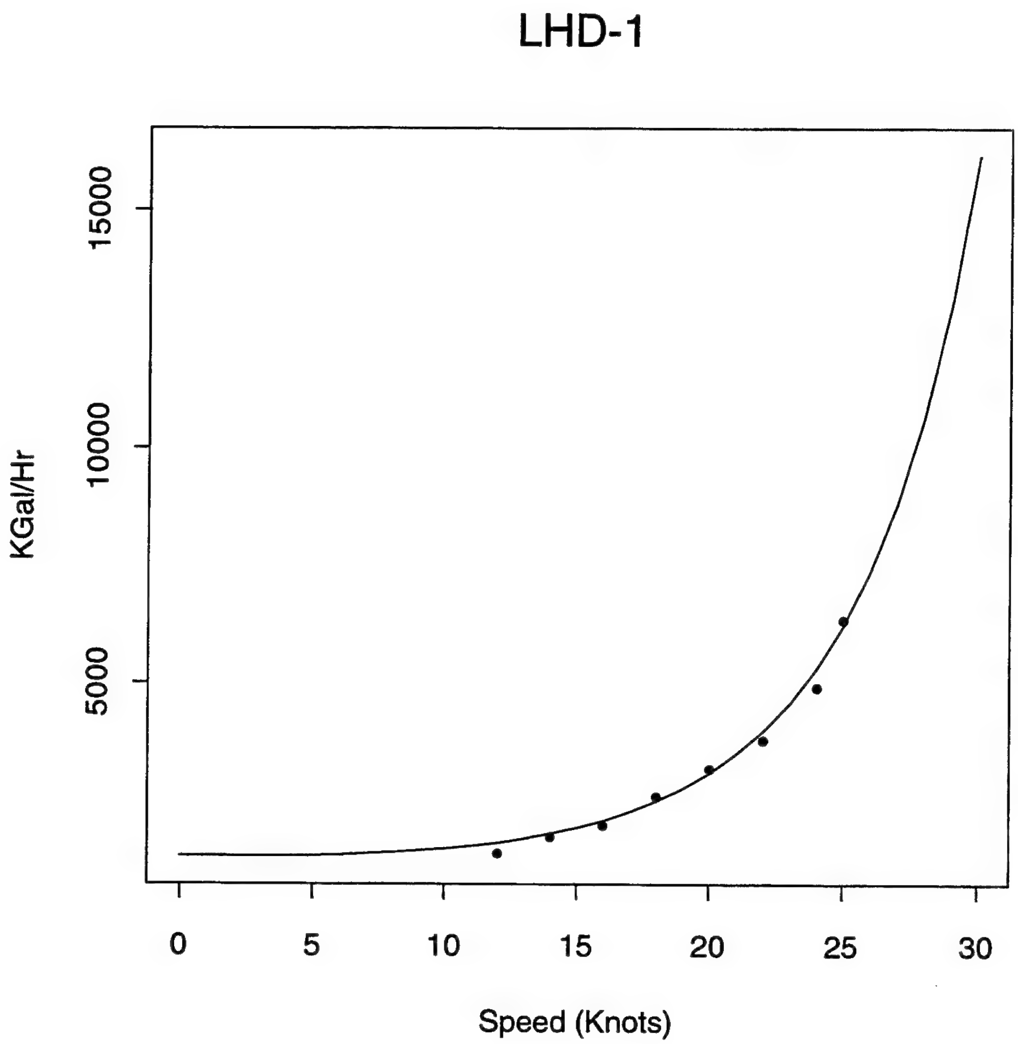
Speed	KGal.Hr	Predicted
0	NA	1338.6
1	NA	1338.8
2	NA	1339.9
3	NA	1342.9
4	NA	1348.8
5	NA	1358.6
6	NA	1373.3
7	NA	1394.0
8	NA	1421.9
9	NA	1458.3
10	NA	1504.5
11	NA	1562.3
12	1489	1633.7
13	NA	1720.9
14	1845	1826.8
15	NA	1954.6
16	2080	2108.7
17	NA	2294.1
18	2700	2517.2
19	NA	2786.4
20	3280	3111.9
21	NA	3507.0
22	3893	3989.2
23	NA	4580.8
24	5000	5311.6
25	6433	6221.0
26	NA	7362.0
27	NA	8806.4
28	NA	10652.4
29	NA	13036.3
30	NA	16148.4
31	NA	20258.5
32	NA	25753.4
33	NA	33193.9
34	NA	43404.8
35	NA	57614.9

Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	78.209	27.5816	2.835550
	-700.811	1458.8500	-0.480386
	2039.410	1276.9900	1.597040

Residual standard error: 216.814 on 5 degrees of freedom


LHD-1
KGal/Hr
15000
10000
5000
0
5
10
15
20
25
30
Speed (Knots)

Class: LHA-1
Source: COMPHIBRON 9

Speed	KGal.Hr	Predicted
0	NA	952.5
1	NA	952.7
2	NA	954.5
3	NA	959.4
4	NA	968.9
5	961.8	984.6
6	NA	1008.2
7	NA	1041.2
8	NA	1085.3
9	NA	1142.4
10	NA	1214.4
11	NA	1303.4
12	1398.6	1411.7
13	1570.8	1541.8
14	1751.4	1696.6
15	1936.2	1879.3
16	2100.0	2093.8
17	2242.8	2344.3
18	2499.0	2635.8
19	2977.8	2974.4
20	3498.6	3366.8
21	3897.6	3821.6
22	4300.8	4348.5
23	4888.8	4959.5
24	5703.6	5669.1
25	NA	6494.5
26	NA	7457.2
27	NA	8583.3
28	NA	9905.0
29	NA	11462.3
30	NA	13304.9
31	NA	15495.5
32	NA	18112.9
33	NA	21257.2
34	NA	25056.4
35	NA	29675.2

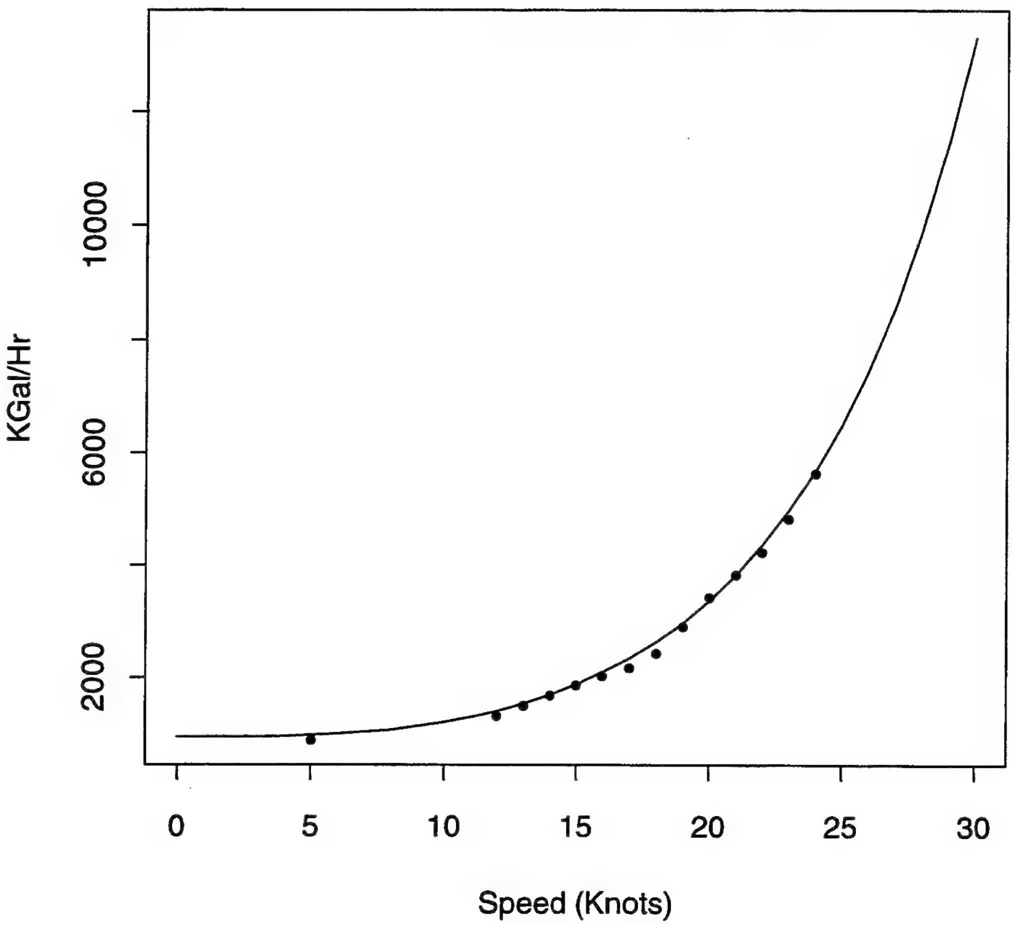
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	39.3264	8.20849	4.79093
	-5577.6800	1811.58000	-3.07890
	6530.1500	1768.23000	3.69305

Residual standard error: 78.8921 on 11 degrees of freedom

LHA-1



Class: LPH-2
Source: COMPHIBRON 9

Speed	KGal.Hr	Predicted
0	NA	475.6
1	NA	475.7
2	NA	476.5
3	NA	478.8
4	NA	483.2
5	504.0	490.5
6	NA	501.3
7	NA	516.2
8	NA	535.8
9	NA	560.5
10	579.6	590.8
11	621.6	626.8
12	663.6	668.7
13	714.0	716.5
14	768.6	769.9
15	831.6	828.5
16	898.8	891.8
17	966.0	959.0
18	1029.0	1029.4
19	1100.4	1101.8
20	1171.8	1175.3
21	NA	1248.7
22	NA	1321.0
23	NA	1391.1
24	NA	1458.1
25	NA	1521.0
26	NA	1579.3
27	NA	1632.3
28	NA	1679.9
29	NA	1721.9
30	NA	1758.3
31	NA	1789.3
32	NA	1815.3
33	NA	1836.7
34	NA	1854.0
35	NA	1867.7

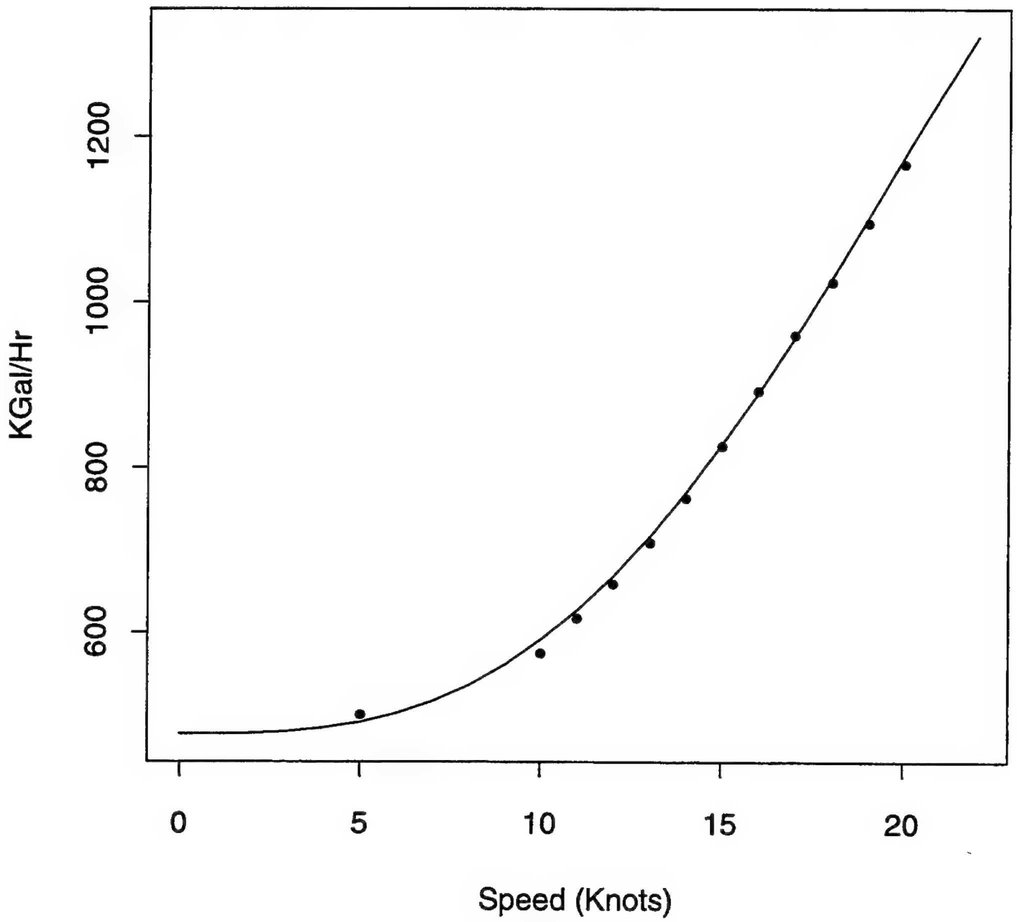
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	-83.8886	9.50305	-8.82755
	1906.9000	117.77400	16.19120
	-1431.3100	113.67300	-12.59150

Residual standard error: 7.37016 on 9 degrees of freedom

LPH-2



Class: LPD-4/AGF-11
Source: COMPHIBRON 9

Speed	KGal.Hr	Predicted
0	NA	442.4
1	NA	442.5
2	NA	443.6
3	NA	446.4
4	NA	452.0
5	462.0	461.2
6	NA	475.0
7	NA	494.5
8	NA	520.8
9	NA	555.3
10	592.2	599.3
11	651.0	654.6
12	726.6	723.4
13	814.8	808.0
14	919.8	911.6
15	1041.6	1038.0
16	1184.4	1192.1
17	1369.2	1380.0
18	1608.6	1609.6
19	1902.6	1891.2
20	2234.4	2238.3
21	NA	2668.5
22	NA	3205.4
23	NA	3881.1
24	NA	4739.0
25	NA	5839.0
26	NA	7264.5
27	NA	9133.6
28	NA	11614.6
29	NA	14951.4
30	NA	19502.1
31	NA	25799.6
32	NA	34649.4
33	NA	47287.4
34	NA	65640.3
35	NA	92761.4

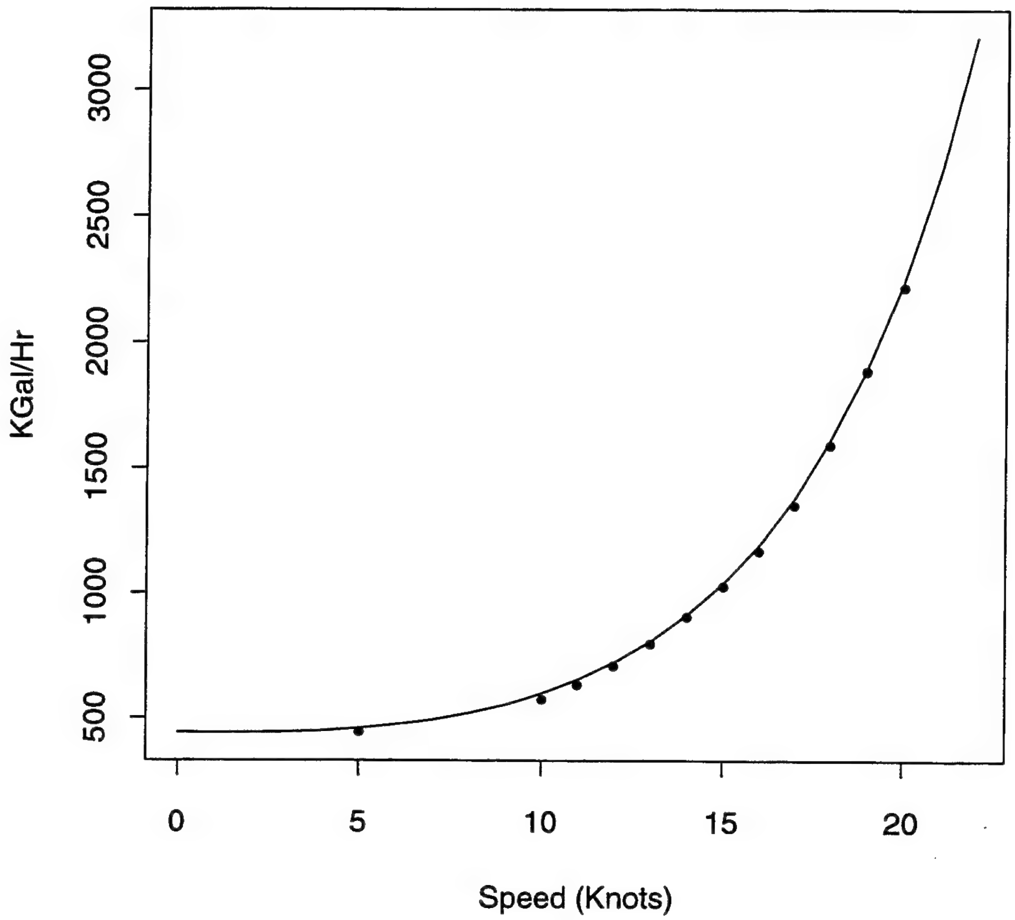
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	95.4647	3.81939	24.9947
	-1124.4300	94.06040	-11.9543
	1566.7900	89.75880	17.4556

Residual standard error: 7.61684 on 9 degrees of freedom

LPD-4/AGF-11



Class: AGF-3
Source: COMPHIBRON 9

Speed	KGal.Hr	Predicted
0	NA	306.2
1	NA	306.3
2	NA	307.2
3	NA	309.8
4	NA	314.6
5	378.0	322.7
6	NA	334.8
7	NA	351.8
8	NA	374.6
9	NA	404.2
10	399.0	441.6
11	NA	488.0
12	529.2	544.7
13	596.4	613.3
14	680.4	695.4
15	789.6	793.0
16	919.8	908.6
17	1058.4	1045.0
18	1230.6	1205.5
19	1407.0	1394.2
20	1591.8	1616.1
21	NA	1877.3
22	NA	2185.1
23	NA	2548.8
24	NA	2979.8
25	NA	3492.7
26	NA	4105.5
27	NA	4841.3
28	NA	5729.8
29	NA	6808.9
30	NA	8128.2
31	NA	9752.3
32	NA	11766.6
33	NA	14284.5
34	NA	17458.1
35	NA	21493.5

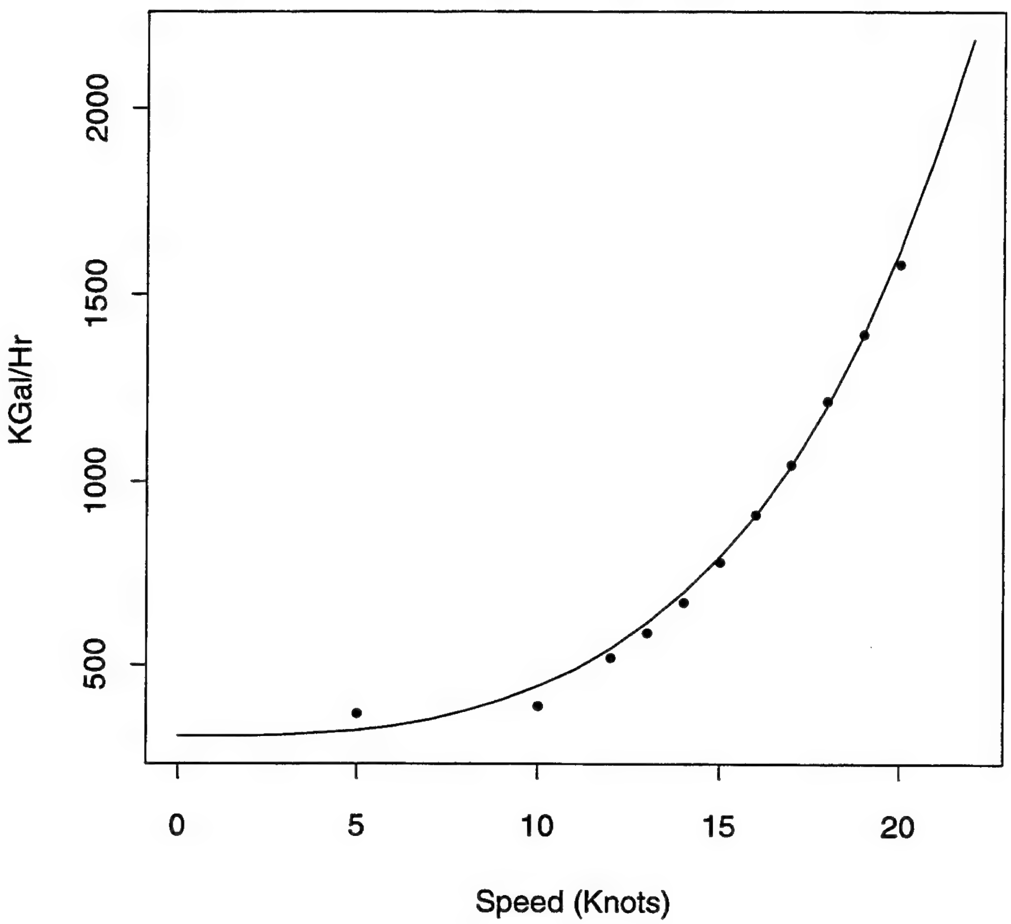
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	52.2391	20.7173	2.52152
	-2218.8100	1246.8100	-1.77959
	2525.0000	1228.5600	2.05525

Residual standard error: 30.2495 on 8 degrees of freedom

AGF-3



Class: LSD-41
Source: COMNAVSURFPAC & COMPHIBRON 7

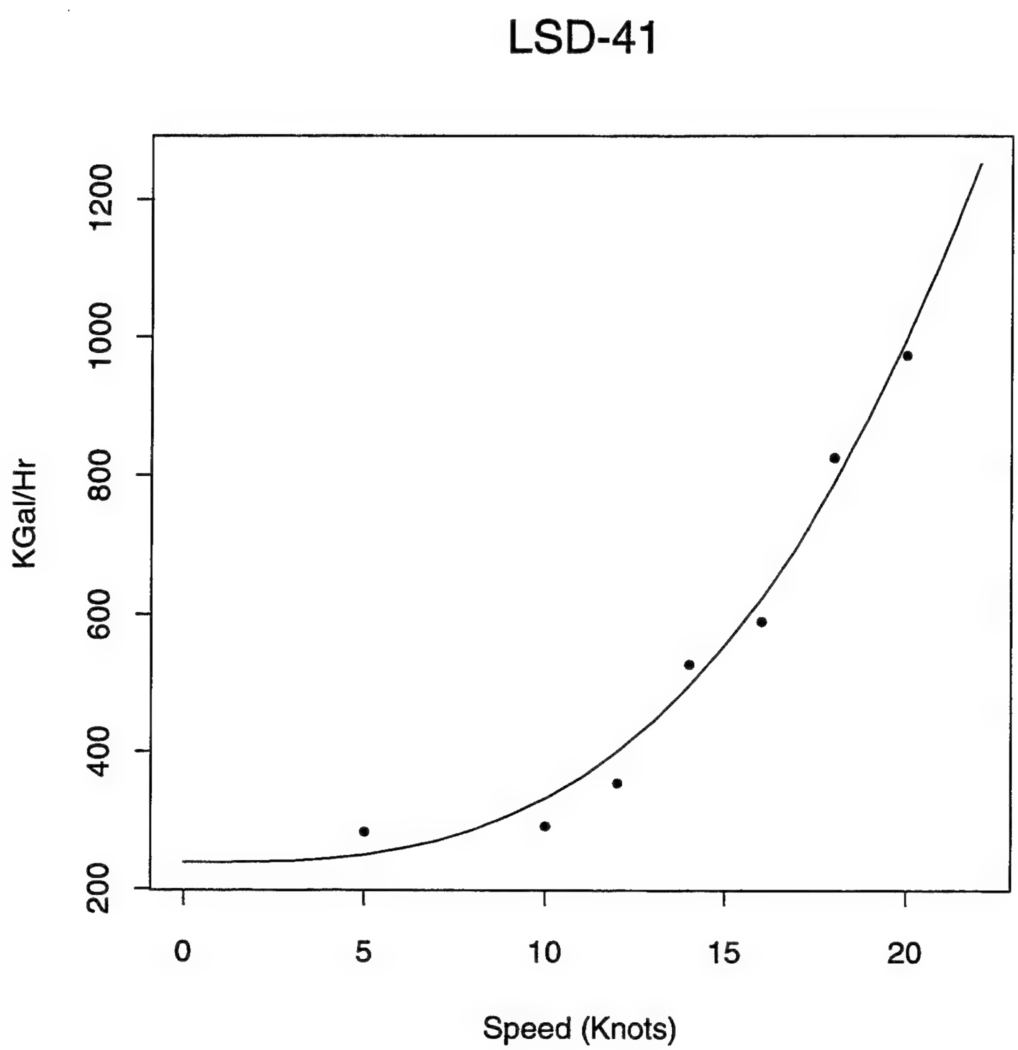
Speed	KGal.Hr	Predicted
0	NA	238.7
1	NA	238.8
2	NA	239.5
3	NA	241.3
4	NA	244.7
5	289.8	250.4
6	NA	258.9
7	NA	270.8
8	NA	286.7
9	NA	307.0
10	298.2	332.4
11	NA	363.5
12	361.2	400.8
13	NA	444.9
14	533.4	496.5
15	NA	556.0
16	596.4	624.2
17	NA	701.7
18	831.6	789.0
19	NA	886.8
20	978.6	995.9
21	NA	1116.8
22	NA	1250.3
23	NA	1397.2
24	NA	1558.1
25	NA	1733.9
26	NA	1925.3
27	NA	2133.2
28	NA	2358.6
29	NA	2602.2
30	NA	2865.1
31	NA	3148.4
32	NA	3453.0
33	NA	3780.2
34	NA	4131.0
35	NA	4506.8

Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	2.86188	62.5409	0.0457601
	-32454.80000	722767.0000	-0.0449035
	32693.50000	722740.0000	0.0452355

Residual standard error: 46.2148 on 4 degrees of freedom



LSD-41
KGal/Hr
200
400
600
800
1000
1200
0
5
10
15
20
Speed (Knots)

Class: LSD-36
Source: COMNAVSUEFPAC & COMPHIBRON 7

Speed	KGal.Hr	Predicted
0	NA	409.0
1	NA	409.1
2	NA	409.9
3	NA	411.9
4	NA	415.8
5	453.6	422.3
6	NA	432.0
7	NA	445.8
8	NA	464.3
9	NA	488.6
10	491.4	519.7
11	NA	558.8
12	588.0	607.4
13	NA	667.3
14	739.2	740.8
15	NA	830.7
16	961.8	940.5
17	NA	1074.7
18	1239.0	1239.1
19	NA	1441.4
20	1688.4	1691.6
21	NA	2003.0
22	NA	2393.2
23	NA	2886.6
24	NA	3516.3
25	NA	4328.1
26	NA	5386.6
27	NA	6783.6
28	NA	8651.0
29	NA	11181.7
30	NA	14661.1
31	NA	19518.3
32	NA	26407.9
33	NA	36344.4
34	NA	50927.0
35	NA	72719.0

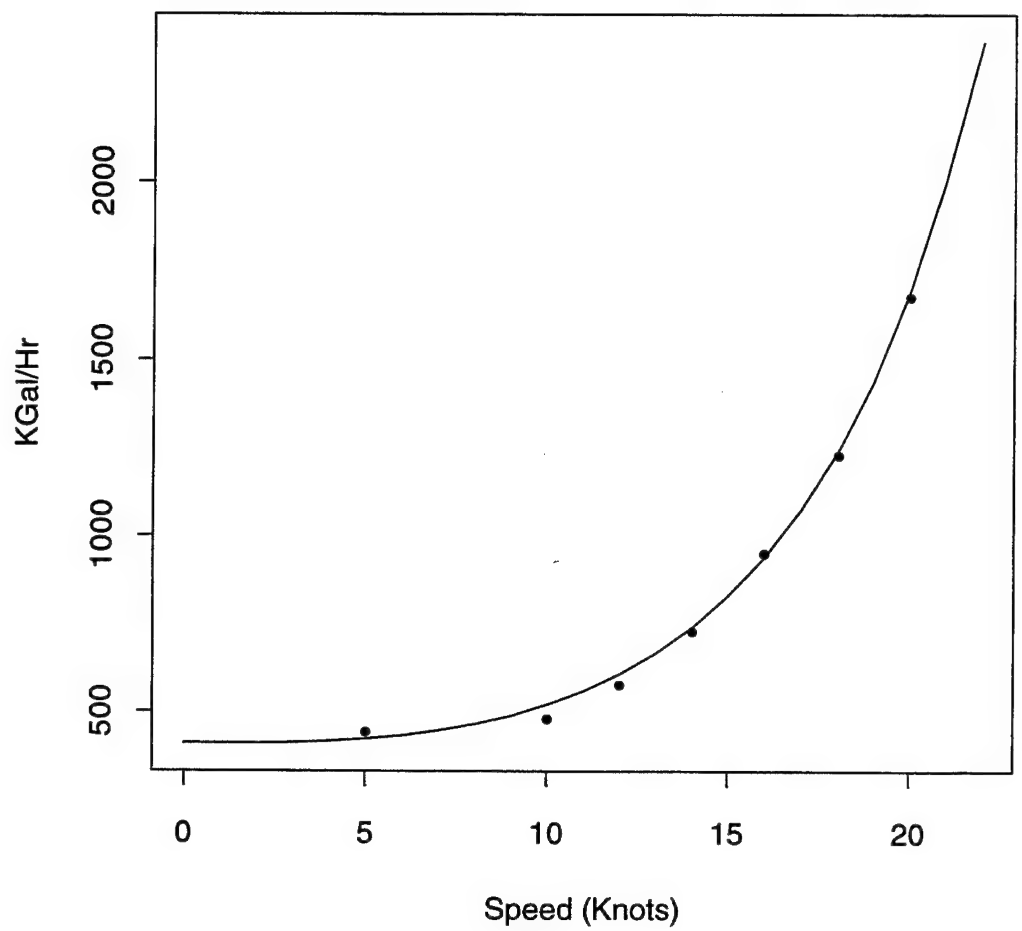
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	98.678	20.8562	4.73136
	-657.897	343.2460	-1.91669
	1066.930	328.0590	3.25227

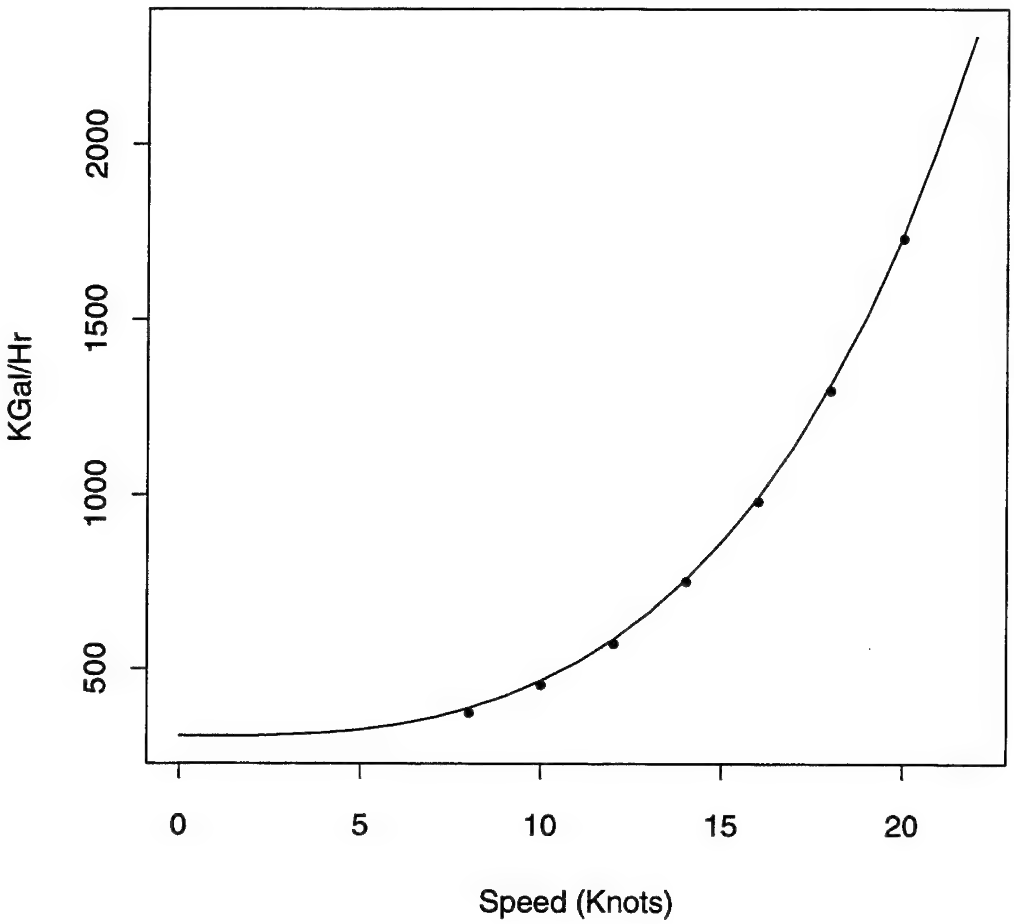
Residual standard error: 25.6232 on 4 degrees of freedom

LSD-36



```
Class: AD-37
Source: NWP 11-2(B)

 Speed KGal.Hr Predicted
     0      NA     306.8
     1      NA     306.9
     2      NA     308.0
     3      NA     311.0
     4      NA     316.8
     5      NA     326.4
     6      NA     340.7
     7      NA     360.7
     8     386     387.5
     9      NA     422.1
    10     466     465.7
    11      NA     519.4
    12     584     584.7
    13      NA     663.0
    14     760     755.8
    15      NA     865.0
    16     992     992.6
    17      NA    1141.0
    18    1310    1312.9
    19      NA    1511.3
    20    1741    1739.8
    21      NA    2002.7
    22      NA    2305.0
    23      NA    2652.5
    24      NA    3052.3
    25      NA    3512.6
    26      NA    4043.6
    27      NA    4657.3
    28      NA    5368.3
    29      NA    6194.5
    30      NA    7157.6
    31      NA    8284.4
    32      NA    9608.0
    33      NA   11169.4
    34      NA   13019.9
    35      NA   15223.9

Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
       Value Std. Error  t value
b     33.4188    2.15993  15.4721
  -4368.6500  348.04700 -12.5519
   4675.4300  346.06200  13.5104

Residual standard error: 2.76573 on 4 degrees of freedom
```

AD-37



Class: AOE-6
Source: NAVSEA 03XN

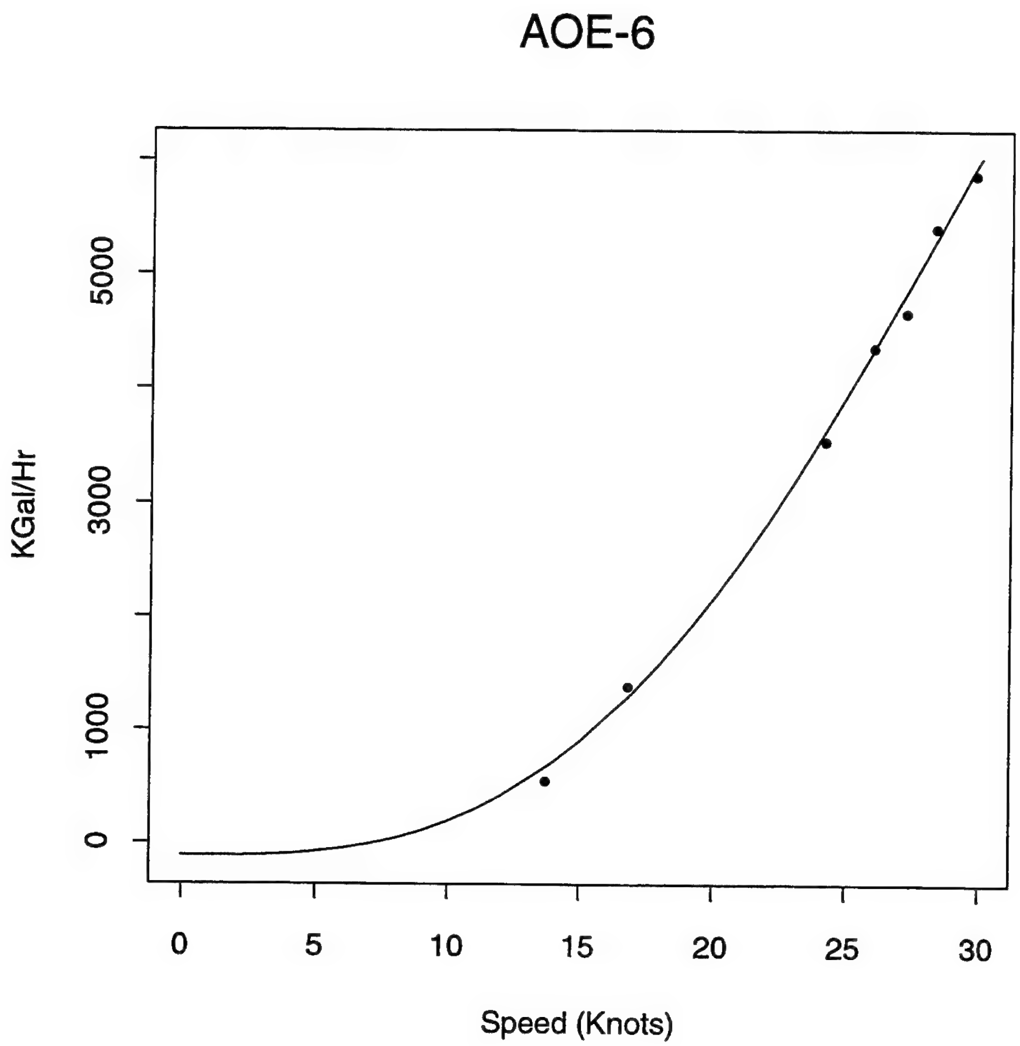
Speed	KGal.Hr	Predicted
0.0	NA	-115.2
1.0	NA	-114.8
2.0	NA	-112.6
3.0	NA	-106.6
4.0	NA	-95.0
5.0	NA	-75.8
6.0	NA	-47.2
7.0	NA	-7.4
8.0	NA	45.3
9.0	NA	112.6
10.0	NA	196.2
11.0	NA	297.6
12.0	NA	417.9
13.7	580	669.6
14.0	NA	720.5
15.0	NA	904.4
16.8	1420	1292.7
17.0	NA	1340.4
18.0	NA	1592.8
19.2	NA	1925.5
20.0	NA	2165.0
21.0	NA	2483.4
22.0	NA	2821.9
23.0	NA	3178.9
24.2	3575	3629.4
25.0	NA	3941.5
26.0	4390	4342.6
27.2	4695	4836.9
28.3	5435	5298.8
29.8	5910	5935.0
30.0	NA	6019.9
31.0	NA	6443.3
32.0	NA	6862.5
33.0	NA	7274.9
34.0	NA	7677.6
35.0	NA	8068.1

Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	-25.7866	8.92627	-2.88885
	12117.2000	2993.10000	4.04836
	-12232.3000	2873.71000	-4.25663

Residual standard error: 131.131 on 4 degrees of freedom


AOE-6
KGal/Hr
0
1000
3000
5000
0
5
10
15
20
25
30
Speed (Knots)

Class: AOE-1
Source: NWIP 11-20(D)

Speed	KGal.Hr	Predicted
0	NA	267.8
1	NA	268.1
2	NA	270.5
3	NA	277.0
4	NA	289.6
5	NA	310.5
6	NA	341.6
7	NA	385.0
8	NA	443.0
9	NA	517.5
10	NA	610.9
11	NA	725.4
12	NA	863.4
13	NA	1027.2
14	1259	1219.5
15	1470	1442.9
16	1712	1700.3
17	1980	1994.8
18	2300	2329.5
19	2690	2708.1
20	3100	3134.3
21	3560	3612.3
22	4150	4146.7
23	4750	4742.5
24	5440	5405.2
25	6130	6140.9
26	7000	6956.4
27	7930	7859.3
28	8780	8858.1
29	NA	9962.2
30	NA	11182.4
31	NA	12530.5
32	NA	14020.3
33	NA	15667.0
34	NA	17488.1
35	NA	19503.5

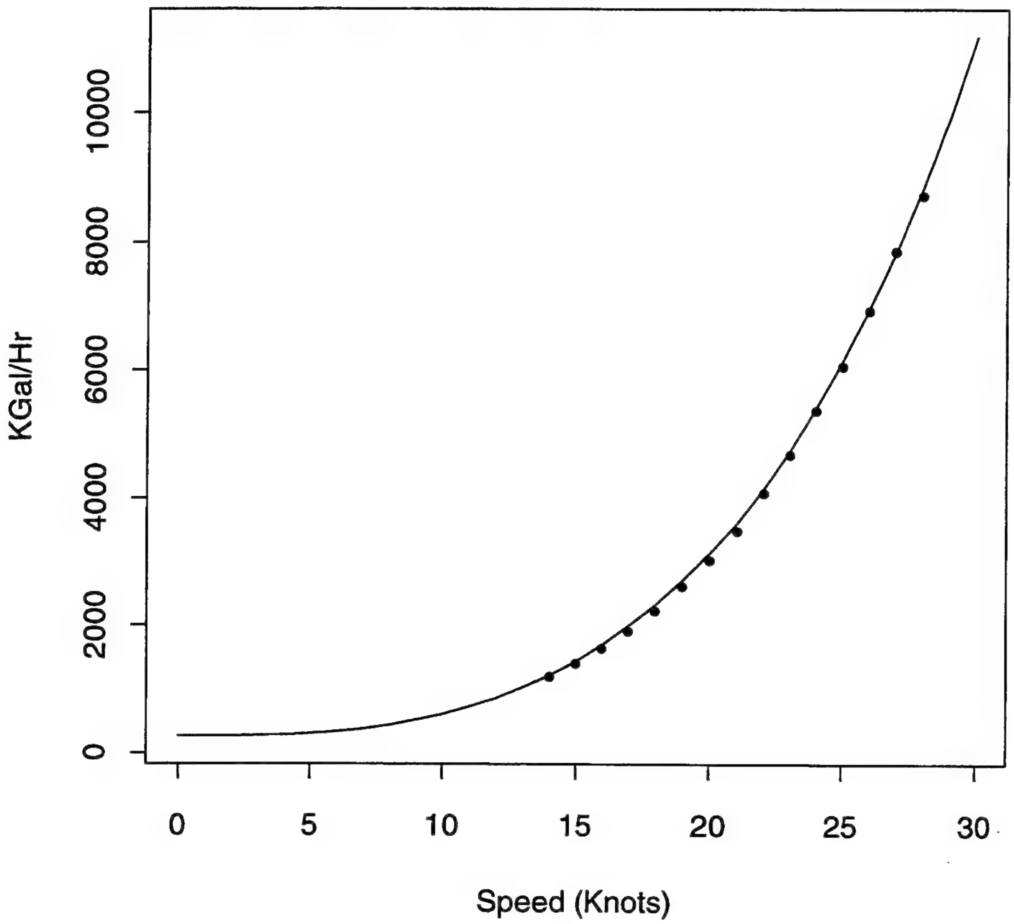
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	12.2579	1.7891	6.85145
	-27553.4000	4703.1800	-5.85846
	27821.2000	4668.4700	5.95939

Residual standard error: 42.9629 on 12 degrees of freedom

AOE-1

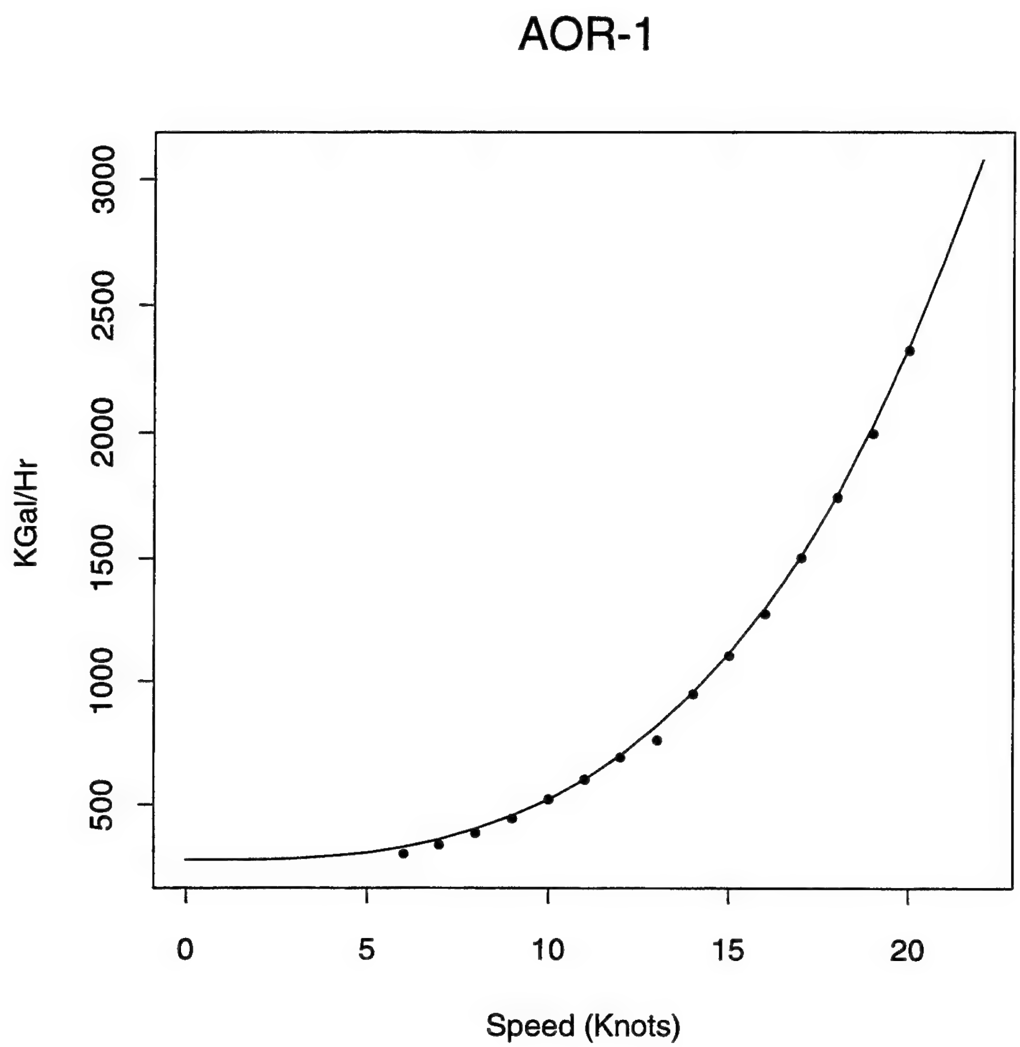


KGal/Hr
0
2000
4000
6000
8000
10000
0
5
10
15
20
25
30
Speed (Knots)

Class: AOR-1
Source: NWIP 11-20(D)

Speed	KGal.Hr	Predicted
0	NA	280.3
1	NA	280.5
2	NA	282.2
3	NA	286.8
4	NA	295.7
5	NA	310.4
6	321	332.3
7	358	363.0
8	404	403.9
9	462	456.5
10	538	522.6
11	619	603.7
12	707	701.5
13	778	817.9
14	965	954.8
15	1120	1114.2
16	1290	1298.4
17	1517	1509.8
18	1760	1751.0
19	2010	2024.9
20	2340	2334.6
21	NA	2683.7
22	NA	3076.1
23	NA	3516.2
24	NA	4008.9
25	NA	4559.9
26	NA	5175.4
27	NA	5862.6
28	NA	6629.7
29	NA	7485.9
30	NA	8442.1
31	NA	9510.5
32	NA	10705.2
33	NA	12042.7
34	NA	13542.0
35	NA	15225.3

```
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
          Value Std. Error  t value
b       16.3917    6.05011  2.70932
    -14380.5000 5760.32000 -2.49647
     14660.8000 5754.35000  2.54777

Residual standard error: 15.4594 on 12 degrees of freedom
```


AOR-1
3000
2500
2000
1500
1000
500
KGal/Hr
0
5
10
15
20
Speed (Knots)

Class: AE/TAE-26
Source: NWIP 11-20(D)

Speed	KGal.Hr	Predicted
0	NA	193.4
1	NA	193.6
2	NA	194.6
3	NA	197.3
4	NA	202.6
5	NA	211.3
6	NA	224.3
7	NA	242.5
8	NA	266.6
9	NA	297.5
10	NA	336.0
11	NA	382.9
12	NA	439.0
13	520	505.0
14	600	581.6
15	660	669.5
16	750	769.4
17	860	881.8
18	990	1007.3
19	1140	1146.3
20	1325	1299.3
21	1530	1466.5
22	1600	1648.3
23	NA	1844.9
24	NA	2056.4
25	NA	2282.7
26	NA	2523.8
27	NA	2779.6
28	NA	3049.7
29	NA	3333.9
30	NA	3631.6
31	NA	3942.3
32	NA	4265.3
33	NA	4600.0
34	NA	4945.3
35	NA	5300.6

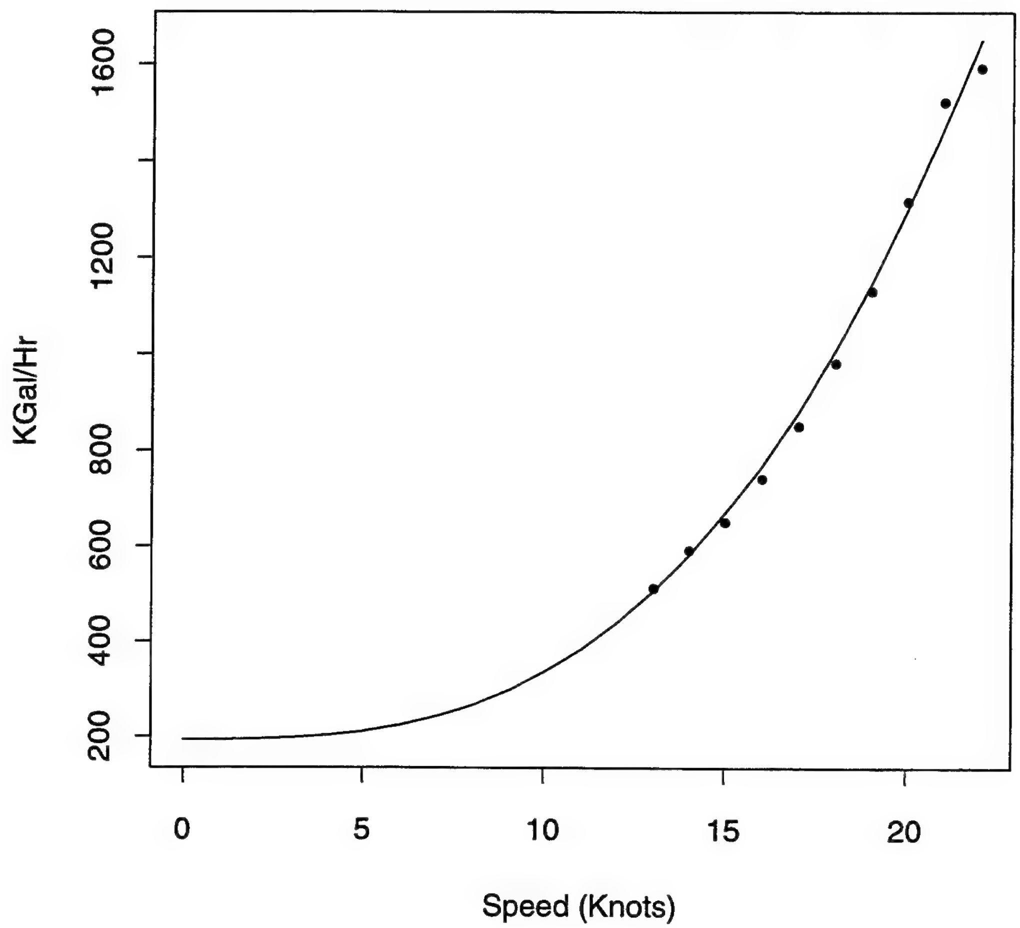
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:

	Value	Std. Error	t value
b	-8.86595	26.0028	-0.340962
	16343.70000	44805.3000	0.364772
	-16150.30000	44747.7000	-0.360919

Residual standard error: 35.6091 on 7 degrees of freedom

AE/TAE-26

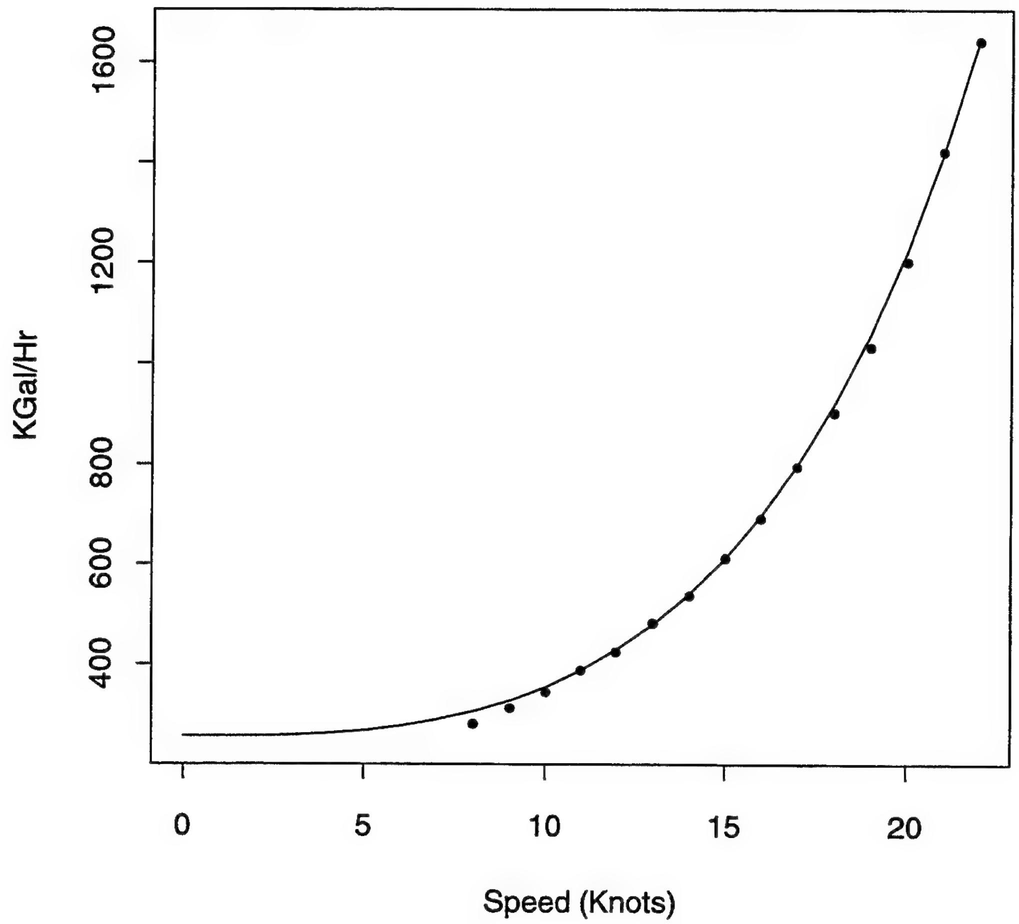


Class: AFS/TAFS-1
Source: NWIP 11-20(D)

Speed	KGal.Hr	Predicted
0	NA	255.8
1	NA	255.9
2	NA	256.6
3	NA	258.4
4	NA	261.9
5	NA	267.8
6	NA	276.6
7	NA	289.0
8	289	305.6
9	321	327.1
10	353	354.4
11	396	388.3
12	433	429.7
13	490	479.9
14	546	540.0
15	620	611.7
16	700	696.8
17	803	797.4
18	910	916.2
19	1040	1056.3
20	1210	1221.6
21	1429	1416.9
22	1650	1648.1
23	NA	1922.5
24	NA	2249.5
25	NA	2640.8
26	NA	3111.2
27	NA	3679.9
28	NA	4371.4
29	NA	5217.8
30	NA	6261.1
31	NA	7557.0
32	NA	9179.4
33	NA	11228.1
34	NA	13838.1
35	NA	17194.6

```
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
        Value Std. Error   t value
b     55.5118    4.56171  12.16910
   -1471.6600  191.51800  -7.68422
    1727.4600  186.86200   9.24459

Residual standard error: 10.0922 on 12 degrees of freedom
```

AFS/TAFS-1

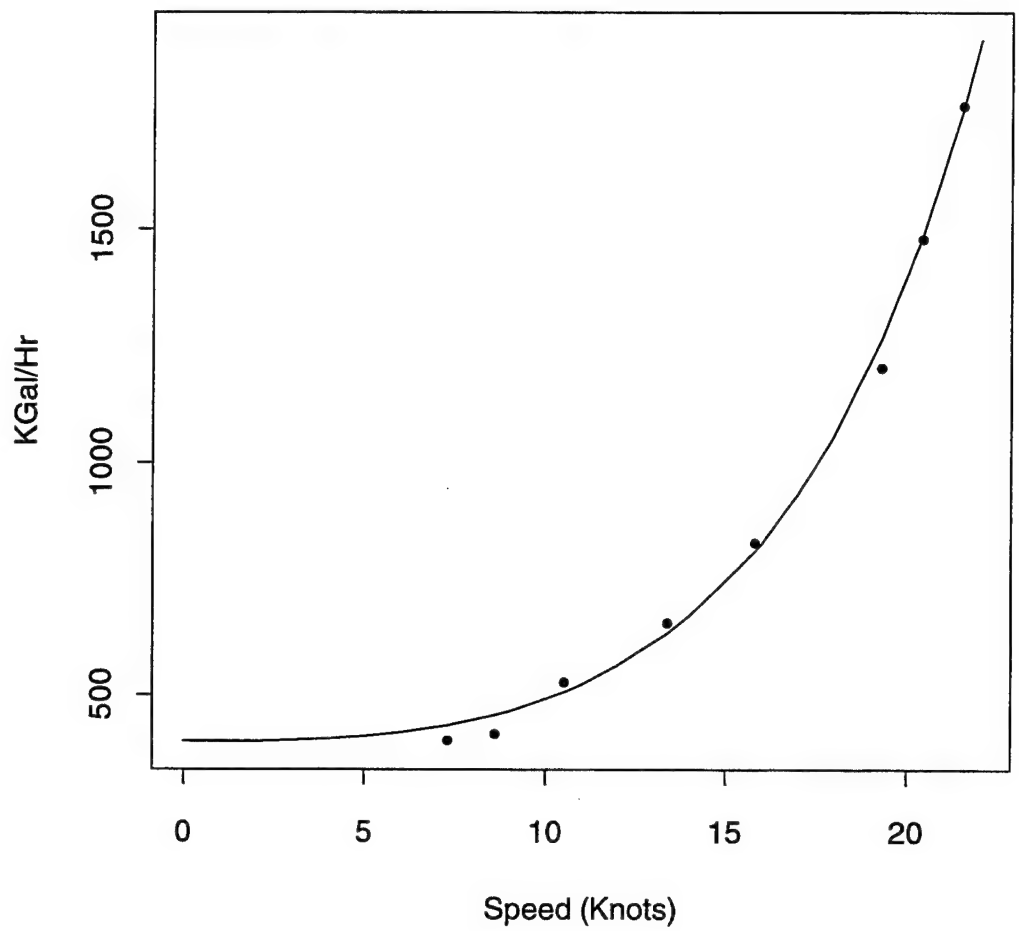


Class: AO-177(J)
Source: NAVSEA Trials

Speed	KGal.Hr	Predicted
0.0	NA	400.3
1.0	NA	400.4
2.0	NA	401.0
3.0	NA	402.7
4.0	NA	405.9
5.0	NA	411.3
6.0	NA	419.4
7.3	412	434.9
8.6	425	457.5
9.0	NA	466.1
10.5	537	506.7
11.0	NA	523.5
12.0	NA	563.0
13.4	663	633.6
14.0	NA	670.3
15.8	837	809.4
16.0	NA	828.0
17.0	NA	932.4
18.0	NA	1058.6
19.3	1212	1263.8
20.4	1487	1483.7
21.5	1775	1758.5
22.0	NA	1905.8
23.0	NA	2252.3
24.0	NA	2684.2
25.0	NA	3227.0
26.0	NA	3915.4
27	NA	4797.0
28	NA	5938.0
29	NA	7431.5
30	NA	9409.5
31	NA	12062.7
32	NA	15668.9
33	NA	20638.9
34	NA	27588.4
35	NA	37454.0

```
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
       Value Std. Error  t value
b    83.9283     25.061  3.34896
   -642.2810    476.553 -1.34776
   1042.5700    457.702  2.27784

Residual standard error: 37.6589 on 5 degrees of freedom
```

AO-177(J)

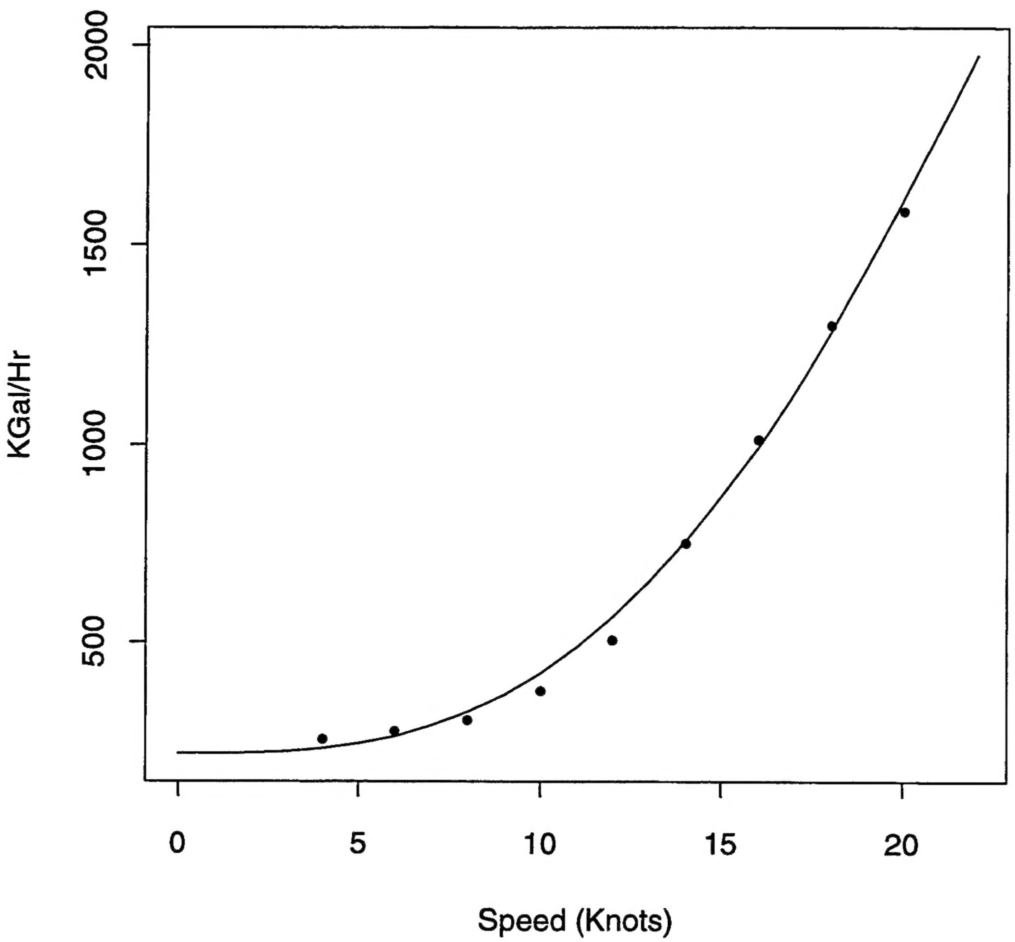


Class: TAO-187
Source: MSC Trials

Speed	KGal.Hr	Predicted
0	NA	219.7
1	NA	219.9
2	NA	221.4
3	NA	225.3
4	266	233.0
5	NA	245.6
6	288	264.3
7	NA	290.4
8	314	324.8
9	NA	368.5
10	388	422.6
11	NA	487.8
12	515	564.7
13	NA	653.8
14	760	755.4
15	NA	869.5
16	1024	996.0
17	NA	1134.4
18	1310	1284.2
19	NA	1444.4
20	1594	1614.0
21	NA	1791.5
22	NA	1975.5
23	NA	2164.2
24	NA	2356.0
25	NA	2548.8
26	NA	2740.7
27	NA	2930.0
28	NA	3114.7
29	NA	3293.2
30	NA	3464.0
31	NA	3625.6
32	NA	3777.1
33	NA	3917.5
34	NA	4046.3
35	NA	4163.3

```
Formula: KGal.Hr ~ cbind(1, exp(b * (Speed/100)^3))

Parameters:
        Value Std. Error  t value
b    -44.9642    23.4124 -1.92053
    4834.5400  2036.3200  2.37415
   -4614.8100  2024.1100 -2.27992

Residual standard error: 34.8975 on 6 degrees of freedom
```

TAO-187



INITIAL DISTRIBUTION LIST

1.	Defense Technical Information Center 8725 John J. Kingman Rd., STE 0944 Ft. Belvoir, VA 22060-6218	2
2.	Defense Logistics Studies Information Exchange U.S. Army Logistics Management Center Fort Lee, VA 23801	2
3.	Library, Code 013 Naval Postgraduate School Monterey, CA 93943	2
4.	Dean of Research, Code 09 Naval Postgraduate School Monterey, CA 93943	1
5.	Chairman, Department of Operations Research, Code OR Naval Postgraduate School Monterey, CA 93943	1
6.	Deputy Chief of Naval Operations (Logistics) Attn: CDR Robert Drash, Code 422C 2000 Navy Pentagon Washington, DC 20350-2000	1
7.	Commander, U.S. Atlantic Fleet Attn: LCDR Kunz, Code N332C 1562 Mitscher Avenue, Suite 250 Norfolk, VA 23551-2487	1
8.	Office of the Chief of Naval Operations Attn: Mr. Matt Henry, Code N81D 2000 Navy Pentagon Washington, DC 20350-2000	1
9.	Center for Naval Analyses Attn: Dr. Ronald Nickel 4401 Ford Avenue Alexandria, VA 22302-0268	1

10. Commander Second Fleet 1
Attn: J-4 Logistics
FPO AE 09501-6000

11. Commander Third Fleet 1
Attn: N-4 Logistics
FPO AP 96601-6001

12. Commander Fifth Fleet 1
Attn: N-4 Logistics
FPO AE 09501-6008

13. Commander Sixth Fleet 1
Attn: N-4 Logistics
FPO AP 09501-6002

13. Commander Seventh Fleet 1
Attn: N-4 Logistics
FPO AP 96601-6003

14. Commander Naval Surface Force, U.S. Atlantic Fleet 1
Attn: N-4 Logistics
1430 Mitscher Avenue
Norfolk, VA 23551-2494

15. Commander Naval Surface Force, U.S. Pacific Fleet 1
Attn: N-4 Logistics
2421 Vella Lavella Road
San Diego, CA 92155-5490

16. Naval Ship Weapon Systems Engineering Station 1
Attn: Mr. Marvin Miller, Code 4M00
Port Hueneme, CA 93043-5007

17. Naval Sea Systems Command 1
Attn: Mr. Thomas Martin, Code 03X11
2531 Jefferson Davis Highway
Arlington, VA 22242-5160

18. CDR Robert Vassian, SC, USN 2
Department of Operations Research
Naval Postgraduate School
Monterey, CA 93943-5000

19. Senior Lecturer Gordon Smyth 2
Department of Mathematics
University of Queensland
Brisbane, Queensland, AUSTRALIA

20. Professor Charles Calvano 1
Department of Mechanical Engineering
Naval Postgraduate School
Monterey, CA 93943-5000

21. Professor David Schrady 50
Department of Operations Research
Naval Postgraduate School
Monterey, CA 93943-5000